1955

The effect of thin metal films on the thermal transmission properties of textile fabrics.

Anderson, John Joseph

Georgia Institute of Technology

THE EFFECT OF THIN METAL FILMS ON THE THERMAL TRANSMISSION PROPERTIES OF TEXTILE FABRICS

A THESIS

Presented to

The Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

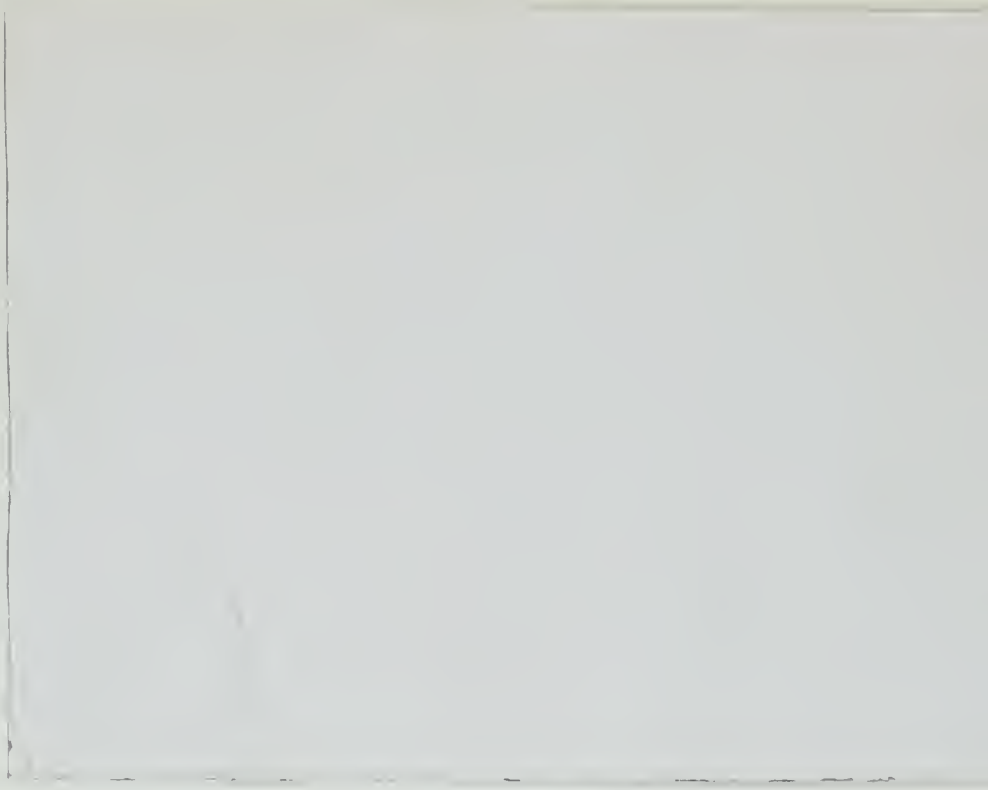
Master of Science in Textile Engineering

By

John Joseph Anderson, Jr.

August 1955

In presenting this dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institution shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or publish from, this dissertation may be granted by the professor under whose direction it was written, or such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.



THE EFFECT OF THIN METAL FILMS ON THE THERMAL TRANSMISSION PROPERTIES OF TEXTILE FABRICS

A THESIS

Presented to

The Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Textile Engineering

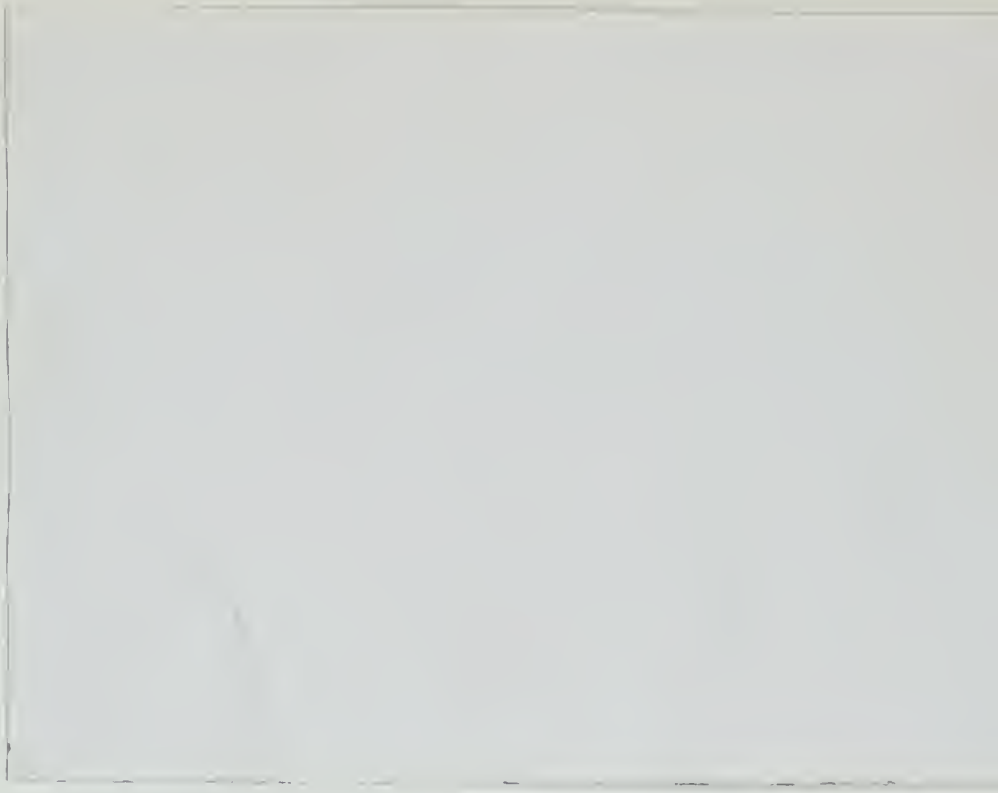
By

John Joseph Anderson, Jr.

August 1955

THE EFFECT OF THIN METAL FILMS ON THE THERMAL TRANSMISSION PROPERTIES OF TEXTILE FABRICS

Approved:



ACKNOWLEDGEMENTS

A sincere expression of gratitude is offered to the United States Navy and the Naval Postgraduate School under the auspices of which this course of study was undertaken; to Dr. James L. Taylor, of the Georgia Institute of Technology Textile School, for his encouragement and understanding while directing the work performed; to Dr. Vernon Crawford, and Dr. H. A. Gersch of the School of Physics, both of whom materially aided in the solving of many of the technical problems which arose, and for the very generous loan of much of the equipment which was used; to Mr. R. B. Belser of the Engineering Experiment Station of the Georgia Institute of Technology, whose knowledge of thin metal films provided the genesis of the major portion of this work, and who also provided the evaporation equipment which was used for metallization of the fabrics.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF ILLUSTRATIONS

SUMMARY

From a search of the literature it appears that very little work has been done concerning the use of infa-red barrier clothing for the purpose of conserving body heat. The investigations which have been conducted appear to be cloaked in the secrecy which so often surrounded war-time research. This lack of information provided great latitude for the selection of areas into which this investigation might be directed. It was felt that insofar as the primary purpose of clothing is the protection of the human body and the conservation of body heat, it would be logical to determine; first, whether or not any tangible increases in fabric insulation could be obtained by the use of a thin metal film; second, the effect of a fabric surface upon the increase in insulating value; third, the effect of weave upon the increase in the thermal insulating value; fourth, the effect of the environmental temperature upon the increase in the insulating value of a fabric.

Eight fabrics were selected because of their different surface characteristics. One sample of each fabric was prepared as the control sample and was untreated, a second sample of the same fabric was metallized with aluminum by the vacuum deposition process. The insulating values were determined by the rate of cooling method in environmental temperatures of -22°F., 0.0°F., 20°F., and 34°F. A second set of five fabrics was selected because of different weave characteristics and prepared in the manner described above. This set of fabrics was tested in an environmental temperature of approximately 35°F., and the insulating value was

determined by the constant cylinder temperature method. In all cases the percentage of increase of the insulating value of the metallized over the untreated fabric was calculated. The emissivity of the fabric before and after metallization was also determined for the purpose of determining the effect of a change of emissivity upon the change of insulating value.

It was found that metallized fabrics can produce increases in the insulating value of up to 28%. In no case did the metallized fabric result in a decrease in insulating value, however, it was determined that metallization of very rough fabrics produce insignificant increases.

It appeared that the weave does have an effect on increases in insulating value and that filament yarns with long floats in the weave are probably the best suited for realization of improved insulating value.

A direct relationship between the emissivity and the percent increase in insulating value was found, and it appears that if fabrics with emissivities in the range of 0.1 can be developed, increases in insulating value far in excess of 28% may be realized.

No significant changes in the percent increase in insulating value were observed as a result of changing the environmental temperature.

CHAPTER I

INTRODUCTION

Food, clothing and shelter comprise the classical list of the necessities of life, and heat is the common denominator of each. Food, loosely speaking, is the fuel which produces body heat; clothing and shelter provide protection for the human body and, in the temperate zones, the retention and conservation of body heat. Man's ability to create and fashion garments, to find or to build shelter and thereby control his environment, represents the major reason why he is able to inhabit vast temperate and arctic areas of the earth. The shelter represents the stationary bases of controlled and artificial environment from which man goes forth to conduct his work. Clothing is the portable control which provides him with the mobility necessary to exist comfortably away from the environment of his shelter.

It was inevitable that man would discover the art of weaving cloth in order to provide himself with clothing of far greater versatility than was provided by animal skins and pelts. There are several examples in nature which are analogous to interlaceings of warp and filling in weaving. Vines often grow in an interwoven network; and birds instinctively weave reeds, straws and twigs in building nests. Probably the best example of a weave, however, is found in the spiders web. In view of these common occurrences, it is not surprising that the art of weaving was developed in widely separated areas of the earth by groups with no intercommunication.

Historical.--Exactly when the art of weaving fabrics from yarns of natural fibers was first attempted and successfully accomplished is unknown. Evidence suggests that Asia was probably the birthplace of the art, however, no definite statement can be made as to the place of origin or the date. Excavations from dry lake beds in Switzerland, Peru and the Nile Valley have produced fabrics which have been variously dated from 12,000 years ago to about 2000 B.C. There is evidence, from coffins found in northern Europe, that wool as well as flax was in use during the second millennium B.C. In spite of this ancient heritage, it is interesting to note that the art was never mastered in some areas such as Melanesia and Polynesia. In these areas cloth was made by the beating of bark and plants (1). One might speculate that weaving was never developed because there was little need for durable and warm cloths in these tropical areas.

Fabrics for cold weather use were, until very recently, selected because the fabric had the ability to reduce the loss of body heat by conduction and convection. The loss of heat which results from wind penetration can usually be controlled by use of a tightly woven fabric, or a fabric which has been coated with a latex or a resin finish. Fabrics which reduce the heat loss by conduction are generally bulky and relatively heavy. This situation arises from the fact that the primary insulating value of most textile fibers is their ability to entrap air and to use the insulating properties of this stagnant air. The warm fibers are also the fibers which have a high degree of resilience and compressibility which enable the fabrics to maintain a near constant entrapment of air. In this connection, and concerning the insulating qualities of wool, Kawsell (2) states, "It can only be concluded that any advantage of wool as a thermal

insulator stems from its ability to maintain its given state of aggregation under end use conditions."

The third method of heat transfer, radiation, has been given relatively little attention. Some investigations of this subject were made immediately before and during World War II and are reported by Fourt and Harris (3). Further amplification of the subject has come from Herrington (4) who states:

> "In order to realize the larger gain in lighter constructions, means would have to be found of preventing contact of the opposed metallized surfaces or any substantial intervening area of fabric and filler. In addition, the fabric surfaces would have to have tested reflectances near 0.95. For applications requiring very low over all conductance, the larger gain cannot be realized for physical reasons related to the nature of the radiation exchange process.
>
> It would not be in order to discard the utility of technically improved reflective fabrics in protective clothing or related applications. A flexible and durable fabric of 0.90 reflectance in the long infra-red would have many applications. At the present moment such fabrics as have been developed seem to have their most direct application when used in connection with fire fighting equipment. Here the requirements for efficient and useful insulation performance are less exacting."

The use and effectiveness of a bright metallic surface for reducing heat transfer was well known to physicists early in the eighteenth century. Investigators such as Rumford and Joule, in calorimetric experiments, used containers of a highly polished metal in order to retard the rate of heat loss between the calorimeter and the surroundings. In 1878 Paclet was aware of the excellence of a bright metallic surface as an insulating medium and used multiple sheets of tin, separated by air spaces, to provide insulation in his experiments. Dewar, in 1892, invented the Dewar Flask. This flask utilized the silvered surfaces of glass as the reflecting medium and was made in the form of a double walled vessel in order to minimize

the effect of heat transfer by radiation between the two walls. (By maintainance of a high vacuum between the two walls of the vessel, heat losses by conduction and convection were practically eliminated also.)

Before 1925 there was practically no commercial utilization of reflective insulation except in the thermos bottle. In 1925, however, Schmidt and Dykerhoff filed patents in Germany for the use of Aluminum foil, less than 0.0005 of an inch thick and in a crumpled form, for commercial use as an insulator. Since that time the uses of reflective insulation has grown tremendously as researchers have found more and more uses and applications which utilize this principle. Today, millions of square feet of reflective insulation are in use on such insulating jobs as cold storage walls, houses, ships, etc. (5).

Deposition of Thin Metal Films.--There are several methods available for the deposition of thin metal films on metallic and non metallic substrates. They are:

1. Burning on
2. Chemical deposition
3. Sputtering
4. Evaporation
5. Reduction from the gaseous phase

The burning on method is applicable for the noble metals which are reduced by heating. This method is especially adapted to deposition on glass or ceramics. The substrate is coated with a layer of an oily solution containing one of the metallic salts. Heat is applied, the oil burns away and the salt is reduced leaving a deposit of the metal. Compounds for this method of deposition for such metals as gold, silver and iridium

are available commercially (6).

Chemical deposition employs the reduction of the metal from a chemical solution. The two best known applications of this method are the Brashear method and the Rochelle salt method. The Brashear method is commonly used in the deposition of thick coats on front-silvered mirrors while the Rochelle salt method, because of its less rapid action, is used in making partially silvered mirrors such as infererometer plates (7).

The phenomenon of sputtering is one which is not fully explained, however the technique has been successfully used for many years. This method involves the use of a vacuum system encompassing a cathode of the metal to be sputtered (and deposited) and a high voltage source. The cathode is bombarded by gaseous ions and metal atoms from the cathode leave in the form of a vapor and are deposited on nearby surfaces. This system allows for a wide range of voltages, 1,000 to 20,000 volts; and a wide range of pressures, from 1 to 10^{-2} mm of mercury (8).

The evaporation of metals in a high vacuum chamber is a procedure which has been practiced for about forty years. By this method, the metal to be evaporated is heated in a high vacuum until its vapor pressure is about 10^{-2} mm of mercury or greater. The metal evaporates radially from the source, usually an electrically heated filament or boat. The vacuum required for this operation is such that the mean free path of the molecules is greater than the diameter of the vacuum container, and the molecular rays are therefore free to propagate from their source to the first cool surface in their path where they are deposited. Heating of the metal in the vacuum chamber is commonly accomplished by placing small loops or hairpins of the metal directly on a filament of tungsten, molybdenum

or tantalum. The filament is heated by electrically connecting it to an electric power supply. The molten metal flows along and coat the filament before being evaporated. Metals which can not be melted by this technique, because of destruction of the filament, can be placed in ceramic boats. These are in turn heated by a filament and evaporation is accomplished in the manner described (9).

Several compounds of metals, such as the carbonyls, can be prepared in the form of a vapor or a gas which can then be forced into contact with a heated surface. The heated surface may reduce the compounds and as a result a thin metal film will form on the surface (10)(11).

Of the five methods of metal deposition described, evaporation is the most suitable for the majority of textile fibers. While this technique employs a hot filament to melt and evaporate the metal, the material to be coated remains relatively cool. Chemical deposition may offer some applications in cases where the chemicals used would not seriously degrade the specific fiber to which the metal was to be applied. The other methods of deposition all involve temperatures well above the range which can be withstood by the common fibers. There are, however, two fibers, glass and asbestos, to which deposition at high temperatures could be successfully accomplished.

Purpose of this Investigation.--As man moves persistently into colder areas, both in the polar regions of the earth and in the upper atmosphere, the need for clothing of greater insulating efficiency increases in importance. The maximum efficiency of clothing can not be realized until a reduction of heat transfer by radiation, as well as conduction and convection, is accomplished. It is toward this end that this investigation is directed.

CHAPTER II

THEORETICAL CONSIDERATIONS

Introduction.--The purpose of cold weather clothing is to protect the human body and to conserve the heat generated within the body. It is therefore desirable to consider some of the heat characteristics of the human body. As in the case of most physiological processes, the regulation of body temperatures, production of heat, distribution and regulation of heat loss are enormously complicated and not fully understood. For this reason, only the salient points will be discussed.

Physiology of Heat Regulation.--The commonly held belief that the body temperature remains constant at 98.6°F. is erroneous. Only the organs deep in the central areas, including the lungs, heart, abdominal organs and the brain are held at this temperature. The remainder of the body undergoes considerable change of temperature, ". . . so that the maintenance of a normal body temperature is quite compatible with considerable gains or losses of heat, with negative or positive heat debt. Areas with variable temperatures are regulated but not at a uniform level." (12). The fact that the skin temperatures will vary, and that the skin temperatures are different for different portions of the body is of considerable importance. This is true because the rate of heat transfer, generally a heat loss, is dependent upon the temperature gradient between the skin and the surrounding media.

The regulation of the body temperature is controlled primarily by the regulation of heat loss from the body and to a lesser extent by the

rate of production of heat. Heat loss from the body takes place by conduction, convection, radiation, evaporation of perspiration and by the inhalation of cool air and the expulsion of heated humid air. The last two methods, evaporation and breathing, account for approximately 24% of the total heat loss from a body at rest, 14% from evaporation from the skin and 10% from the respiratory tract (13). The 14% lost by evaporation from the skin is due to insensible perspiration which is always present even though there is no obvious wetness of the skin.

There are two physiological processes of prime importance in the control of heat loss. To reduce heat loss, the blood vessels near the surface of the skin will contract thereby reducing the amount of blood in the surface tissues and causing the surface tissues to become cooler. This action has a twofold effect; first, it causes a drop in the temperature gradient from the skin to the surroundings and therefore a reduction of heat loss; second, it allows the surface tissues to behave as an insulating medium for the body. To increase the rate of heat loss, the body increases the rate of perspiration. The body then supplies the heat necessary to evaporate the perspiration.

Other methods of controlling the heat loss are a roughening of the skin and the erection of hair to reduce convective loss, and the changing of body position in order to expose a greater or lesser area. The later method is of considerable importance and is employed with great frequency. The position changes are almost always resorted to without conscious direction. Probably the best illustration of this action is the tendency to curl up in a cold bed.

Heat Transfer.--Heat transfer by conduction is a point by point process in which one area of a body is heated directly from a heat source. The heat is then transfered within the body by an increase in molecular motion as neighboring areas become successively heated. The common expression for heat transfer by conduction is:

$$Q = \frac{k \times A \times (T_2 - T_1) \times t}{d} \qquad (1)$$

where, Q = the quantity of heat conducted

k = the thermal conductivity, a constant which depends upon the type of material

A = the area of the conducting surface

$T_2 - T_1$ = the difference in the temperatures of the warm and the cold surfaces

t = time

d = the thickness of the conductor

Natural convective losses are the result of a change of density of a fluid in contact with a warmed body. As the fluid becomes heated by conduction from the warmed body, the density usually decreases and the fluid rises. As the fluid rises it is replaced by a cooler more dense fluid which in turn is heated and rises. This condition produces a continuous flow of fluid past the warm body which carries off heat. Fluids will adhere to surfaces with varying degrees of tenacity. A very thin layer of fluid immediately adjacent to the surface remains at rest in spite of the convective forces. The fluid layers at greater distances from the surface are less attracted to the surface and as a result are

more subject to the convective action.

Loss by convection is therefore a two step process; first, heat is transferred through the stagnant fluid layer by pure conduction; second, heat is transferred from the stagnant layer to the layers of fluid which are streaming past. The expression for computing the heat loss due to convection is based upon the assumption that the heat transferred by convection is the same as the heat transferred or conducted through the still surface of the air near the skin. The equation is (14):

$$H_c = \frac{K \times A \times (T_h - T_a) \times t}{\delta_o} \qquad (2)$$

where, H_c = heat loss by convection

K = thermal conductivity of air

A = the effective surface area

T_h = the average skin temperature

T_a = the average air temperature

δ_o = the thickness of the surface air layer

t = time

Forced convection is another form of convection; it is usually considered to be all convection which is not directly attributable to the natural rising of air in a warm body. Forced convection can result from currents of air generated by the movement of the body or it may be caused by air currents from outside influences such as wind.

Heat transfer by radiation is an exchange of energy between two bodies by means of electromagnetic waves. It is independent of the medium separating the bodies, providing the medium does not absorb or reflect the

energy, but it is dependent upon the temperature of the surfaces and the nature of the surfaces.

The parameter which characterizes the surface is the emissivity. The emissivity is defined as the ratio of heat radiated by a body to the heat which would be radiated by a black body under similar conditions. The reflectivity is equal to one minus the emissivity. When radiant energy impinges upon the surface of an object, a fraction of the energy may be absorbed, a fraction reflected, and a fraction transmitted. In the case of a perfect black body, none of the energy is reflected, and none is transmitted, therefore all of the energy is absorbed. Thus it is stated that the absorptivity of a black body is unity which means that all of the impinging energy is absorbed. Thermodynamical arguments show that the emissivity is equal to the absorptivity. Since most of the materials studied in this program have little or no transmissivity, it may be assumed, for all practical purposes, that the emissivity plus the reflectivity are equal to unity.

If radiant energy is to be emitted from the interior of a solid it must be able to penetrate the surface of the solid without being dissipated by producing other energy changes within nearby molecules. There seems to be little probability that radiant energy generated within a solid will reach the surface without encountering other molecules. It therefore appears that the energy radiated from a solid body originates at or near the surface. Conversely, absorption of radiation will also depend upon the nature of the surface of the solid. Relating this condition to a textile fabric, it can be assumed that each individual fiber on the surface of a fabric will emit radiant energy from its surface, and if the surface

is changed in any way so as to change the emissivity, the emissive power of the fabric will also be changed.

The manner in which temperature affects radiation was stated empirically by Josef Stefan and later deduced theoretically by Ludwig Boltzmann. It is known as the Fourth Power Law for black bodies.

$$E_b = 0.173 \times 10^{-8} T^4$$

The constant 0.173×10^{-8} Btu/hour/foot^2/$^\circ R^4$ is known as the Stefan-Boltzmann constant, and is usually designated by the Greek letter σ. For a nude man the equation for the amount of energy radiated is:

$$H_r = 1.73 \times 10^{-11} (T_s^4 - T_c^4) e_1 e_2 \qquad (4)$$

Where, H_r = Kilo calories/second/square meter

T_s = Average skin temperature in °R

T_c = Environmental temperature in °R

e_1 = Emissivity of the environment

e_2 = Emissivity of the human skin

As can be seen from the foregoing equations, energy is radiated by all bodies which have a temperature above absolute zero. The exact origin of this energy is not fully understood, however, it is believed (15) that radiant energy originates within the molecules of the radiating body and that the atoms of such molecules are vibrating in simple harmonic motion as linear oscillators. The emission of radiant energy is believed to represent a decrease in the amplitude of the vibration while absorption of radiant energy represents an increase in the amplitude. Plank postulated that for every frequency there is a minimum amount of energy which

can be emitted, the quantum. A smaller quantity can not be emitted however many such quanta may be emitted. Therefore, radiant energy for any given frequency can be pictured as consisting of successive pulses of energy.

Measurement Units.--All of the previously discussed modes of heat transfer are present and effective in the process of transfering heat from the human body to its environment. The measurement, however, of the heat transfer which can be attributed to any single one of these three modes is complicated by the fact that the human body is generally clad in several layers of fabric. The fabrics are not, in aggregate or each by itself, a homogenous mass but rather a system of fibers and air spaces. Both the fibers and the air spaces can and do vary considerably. For this reason it is common practice to employ units which will represent the total ability of a fabric to retain heat within the body, or the ability of a fabric to insulate.

There are three methods of expressing the insulating value of a fabric which have received more or less acceptance by investigators in this field. Marsh (16) suggests the use of a term, Thermal Insulation Value (T. I. V.), and Baxter and Cassie (17) elaborate on the term describing it as the percent of heat saved due to presence of a fabric on a heated body. The expression for T.I.V. is:

$$T.I.V. = \frac{(H_o - H_c)}{H_o} \times 100 \qquad (5)$$

where: H_o = heat lost per second from the uncovered surface

H_c = heat lost per second from the covered surface

Another, but less commonly used, unit for measuring thermal resistance is called the TOG. Rees (18) defines the TOG as one tenth of the ratio of the temperature differential causing heat to flow to the actual heat flow in watts per square meter, or:

$$10 \text{ TOGS} = \frac{°C}{\text{Watts/meter}^2} \qquad (6)$$

where: °C = the temperature differential between the warm body and the environment

Watts/meter^2 = Input watts to the heating element divided by the area of the warm body surface

In the determination of TOGS, Rees used an apparatus in which he kept the temperature differential across the fabric constant by controlling the power input to an internal heating element.

The third unit of measurement is one in which the human physiological factors are taken into account. This unit is known as the Clo (19), and it is the insulation necessary to maintain comfort and a mean skin temperature of 92°F. in a room at 70°F. with air movement not over 10 feet per minute, less than 50% humidity, and a metabolism of 50 calories per hour per meter^2.

Fabric Insulating Characteristics.—The ability of a fabric to effectively insulate the human body is due to the ability of the fabric to reduce heat loss by conduction and convection. Some investigators (20)(21)(22) have come to the conclusion that the insulating value of a fabric is primarily due to the fabric thickness. This criterion, however, presents a difficulty because fabrics are generally relatively thin materials with no clearly

defined surfaces. The resultant uncertainties in the thicknesses are of sufficient magnitude in relation to the overall thicknesses to render precise quantitative work difficult.

The density of the fabric is another important consideration. Rees (23) has shown that the thermal transmission of a fabric increases as the density is increased. Morris (24), in commenting on Rees's findings points out that the term fabric density is a vague one and needs special consideration. He points out that properties dependent upon the density of homogeneous materials are consistent, and that measurements of different samples of the same density will give reproducible results. This does not hold true for textiles. Two fabrics of the same density may differ considerably in their structure. One fabric may be made of soft yarns and a high construction while a second fabric may be woven of hard tight yarns but be of a lower construction. Therefore, two fabrics of the same density will differ in their thermal transmission properties. In relating the density to the thickness, Marsh (25) concludes that for any given thickness, the less dense fabrics will show the greatest insulating values.

A comparison of the thermal conductivities of air and several textile fibers reveals why the amount of air entrapped in a fabric is important to the fabrics insulating qualities. The following table shows the relative conductivity of several fibers using the conductivity of air as unity.

Table 1. Relative Conductivity of Textile Fibers

Fiber	Relative Conductivity
Wool	7.3
Cotton	17.5

(Continued)

Table 1. Relative Conductivity of Textile Fibers

(Continued)

Fiber	Relative Conductivity
Viscose	11.0
Polyvinyl chloride-acetate	6.3
Cellulose acetate	8.6
Ethyl cellulose	8.9

In an article concerning warmth, air permeability and resilience, Cassie (26) discusses the manner by which textile materials entrap air. He points out that there are no cells or closed spaces in which to entrap the air. Air clings to a solid surface and the fibers of a fabric present an enormous total surface. The aerodynamic principle of drag is the cause of bringing the air to rest.

Human skin and most textile fabrics have a very high emissivity, 0.95 and above, in the far infa-red region of the electromagnetic spectrum (27). This fact gives rise to a situation whereby excellent conditions for heat loss by radiation are present so long as an air space intervenes between the skin and fabric or between fabric and fabric. The nature of a fabric and the methods of clothing the human body provide a large percentage of areas where air spaces will intervene.

Literature Survey of Infa-red Barrier Clothing.—Metals are the only materials which show high reflection of radiation throughout the infa-red regions. The problem which presents itself is how to make use of metals in conjunction with fabrics so that radiant energy will be reflected. The metals must be exposed to the radiation without an intervening material

and therefore can not be woven as an integral part of the yarns making up the fabric. If the fabric itself is coated with a metallic surface, in the many areas of the body about which clothing fits tightly, some means of providing an air space will have to be devised. The metal surfaces will have to be kept free from contaminating influences. Taylor and Edwards (28) have shown that if a metallic surface is coated with a lacquer to protect the surface, even though the coating is no more than 1 micron thick, a highly emissive surface is introduced and the ability of the metal to reflect the radiant energy is greatly reduced.

Fourt and Harris discuss part of the results of one attempt to make use of a thin metal film for reducing heat transfer. The data presented was obtained from unpublished results of a project conducted by the Harris Laboratories. In this test two fabrics were metallized by vacuum deposition procedures. The metal surfaces were arranged to face each other and were separated by an open knit fabric. The introduction of the metal surface gave increases up to approximately 30% in the thermal resistance.

Fourt and Harris also comment (29) on the practicality of using the arrangement of such a sandwich structure as the one tested by the Harris Laboratories.

> The chief obstacle to the use of sandwich systems for protective clothing is that the total insulation required for flying clothing is greater than that which can be reached by a single sandwich of one spacer between two barrier layers. When additional sandwich layers are added to increase the total resistance, the resistance contributed by each unit decreases, and the thermal effectiveness (resistance per unit weight) of the system as a whole goes down. The conclusion of this wartime study was that it was not practicable to make purely insulative clothing with enough total resistance to meet the needs of unheated avaiation

clothing. The possibility remains open of some advantages in connection with heated flying clothing, if the difficulties of garment assembly and of providing a durable, highly reflecting layer can be solved. It should be noted that gains in insulation from radiation barriers tend to be lost by increased convective loss through the open meshes of the spacer. An infa-red barrier used as the outside surface is also sensitive to wind, because for a given thermal resistance an infa-red barrier will have a higher surface temperature. The dilemma confronting the designer of infa-red barrier clothing of high thermal efficiency is the fact that the barrier has more effect, the larger the thermal gradient, but that large thermal gradients in clothing promote convection losses.

Metallized cloth, cotton and asbestos, is being utilized and marketed commercially. The Minnesota Mining and Manufacturing Company is producing fabrics which are coated with aluminum deposited by a vacuum process. To date these fabrics have found use in areas such as protective clothing for fire fighters and steel mill operations where intense heat is present. The clothing is designed with the aluminum surface out in order to reflect the radiant energy which is generated by the high temperatures. Considerable success has been achieved in this application (30).

CHAPTER III

INSTRUMENTATION AND EQUIPMENT

All of the equipment used in the analysis of the fabric samples are standard to most textile testing laboratories and require no special identification. The list includes such items as the Gurley Densometer, Randall and Stickney Thickness Gage, pick glass and an analytical balance.

Evaporation Equipment.--The evaporation equipment consisted of a series arrangement of a Cenco Megavac forepump, and an oil-diffusion high-vacuum pump of approximately four inch bore. Evaporation was accomplished in a bell jar of approximately five liter capacity. Inside the bell jar were two electrodes connected by a tungsten filament which was made up of two strands of 20 mil wire. The power supply for the filament was a Variac and transformer combination which supplied up to 10 volts and 100 amperes. Pressure within the bell jar was measured with an R.C.A. Ionization Gauge, Type EMG-1. This equipment is shown in Figure 1. A circular rack was used to suspend the fabric samples around the filament and was arranged so that the center of the sample was level with the filament.

Fabric Insulation Test Apparatus.--The equipment used in determining the Thermal Insulation Value consisted of the following items.

Voltmeter, 0 - 10 volts, D.C., Simpson Model 29

Ammeter, 0 - 2 amps, D.C., Simpson Model 29

Rheostat, 7 ohms

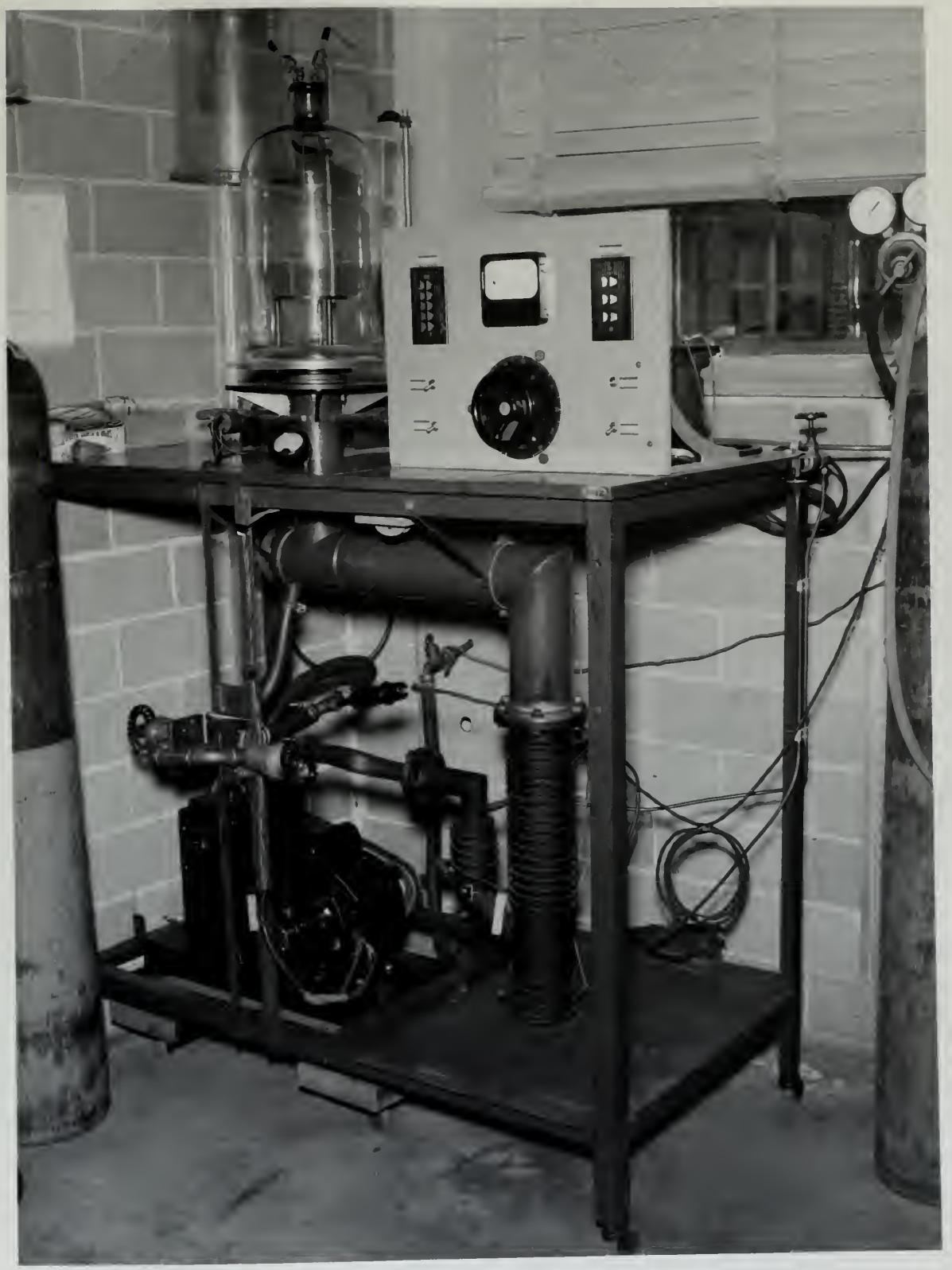


Figure 1. Evaporation Equipment

Galvanometer, Weston Model 440, 1 division equals 2.2×10^{-6} amps approximately, 3.7 ohms

One ohm galvanometer shunt

Mechanically refrigerated cold chamber

A wide mouth thermos constant temperature bath with cracked ice

Fabric insulation test cylinder

Stop watch

Copper-constantan thermocouple with hot and cold junctions

The heating circuit was supplied from a 6 volt lead storage battery. The rheostat was connected in series with the ammeter and the heating element. The voltmeter was connected directly across the heating element. The test cylinder temperatures were determined by using the galvanometer.

The insulation test cylinder was constructed of 7/8 inch O.D. copper tubing with a wall thickness of 0.035 inches. It was sealed at the top with a copper plate of the same thickness as the wall, and the bottom was mounted on a one inch Pine dowel. A nichrome wire heating element of approximately 2.7 ohms was enclosed within the cylinder with asbestos paper used for electrical insulation. The hot junction of the thermocouple was soldered directly to the outside of the cylinder midway between the top and bottom. The cylinder was painted with ordinary flat black oil paint in order to simulate black body conditions of human skin.

A ribbed knit sock of an ordinary undershirt was placed over the cylinder. This sock was then covered with another knit sock of an elliptical Saran monofilament with a cross section 0.013 x 0.030 inches. The second sock was of a very loose knit and provided approximately a 1/16 inch air space between the cotton undershirt and the fabric being tested.

Approximately 1/2 inch of each knit sock extended below the copper cylinder and down on to the dowel. This portion of the socks was covered with one layer of ordinary plastic electrical tape. The testing cylinder can be seen in the upper left of Figure 2.

Approximately 93% of the surface of the cylinder was exposed to the fabric and the remaining 7% faced the dowel on which the cylinder was mounted. On this basis, it was concluded that a minimum of 93% of the heat generated in the cylinder would pass through the test fabric provided the resistance to the heat flow through the fabric was equal to or less than the resistance offered by the wood dowel. Actually, this percentage would be considerably higher because the fabric samples were cut sufficiently large so that they would extend one and one half inches down the dowel. Therefore, any heat escaping from the dowel surface in this covered area would still pass through the fabric. In addition, the wood has a low thermal conductivity and would offer considerably more resistance to the heat flow than would the relatively thin fabrics which were being tested. In view of the fact that comparative rather than absolute values were desired, it was concluded that the testing cylinder would yield reasonably accurate results.

Emissivity Measurement Equipment.--The method and apparatus used for the determination of the emissivity is described by Kern (31).

> A hollow, opaque, internally blackened cylinder is maintained in a constant-temperature bath. A total radiation receiver is mounted by a bracket to the wall of the cylinder. The radiation receiver consists of a copper cylinder a, which is blackened on the inside and highly polished on the outside. Two extremely thin, blackened, and highly conducting copper discs b and b' are mounted in the receiver for the purpose

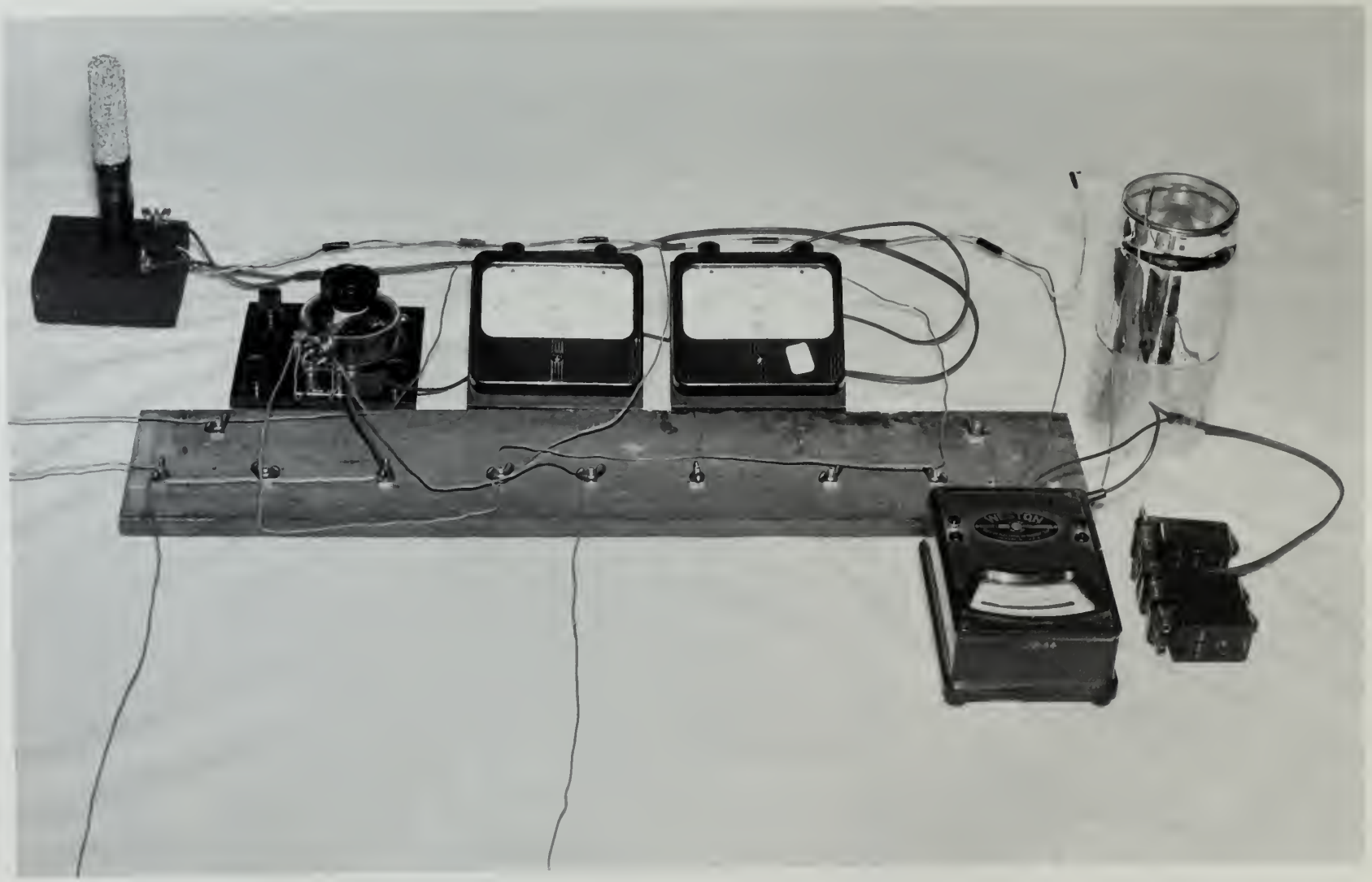


Figure 2. Fabric Insulation Test Apparatus

> of absorbing radiation. By mounting the discs at equal distance from the top and bottom of the small cylinder, the angles $alpha_1$ and $alpha_2$ are equal and the discs have equal areas for receiving radiation. The lower disc receives radiation from the blackened constant-temperature walls of the vessel. The upper disc receives radiation from a plate of specimen material c which is electrically maintained at a fixed temperature. The two discs are wired together by a sensitive thermocouple so that they oppose each other, and only net differences in the quantity of radiation are measured by the galvanometer. By wiring them to oppose each other, any effects within the receiver itself are also cancelled. If the galvanometer deflection for the specimen non-black body is measured and then c is replaced by a perfect black body, the ratio of the two galvanometer deflections is the emissivity of the specimen. Data obtained in this manner are the normal total emissivity. . . .

Figure 3 is Kern's diagram of this apparatus.

The emissivity measuring device for this experiment was constructed of the following materials.

Hollow cylinder	404 x 700 tin can
Copper cylinder	1 5/8 inch copper tubing
	3 5/8 inches long
Copper discs	0.005 inch copper sheet
Thermocouples	copper-constantan

All of the blackened surfaces were obtained by first painting the surface with a thin coat of spar varnish and immediately rubbing the surface with lampblack. By using copious quantities of lampblack it was found that the varnish surface could be completely covered and a pure lampblack surface evolved. The surface thus obtained, while not durable, held up satisfactorily during the course of this experiment. Figure 4 gives a view of the actual apparatus.

The difference of the E.M.F. generated by the two internal thermocouples was measured by a potentiometer rather than a galvanometer as suggested by Kern.

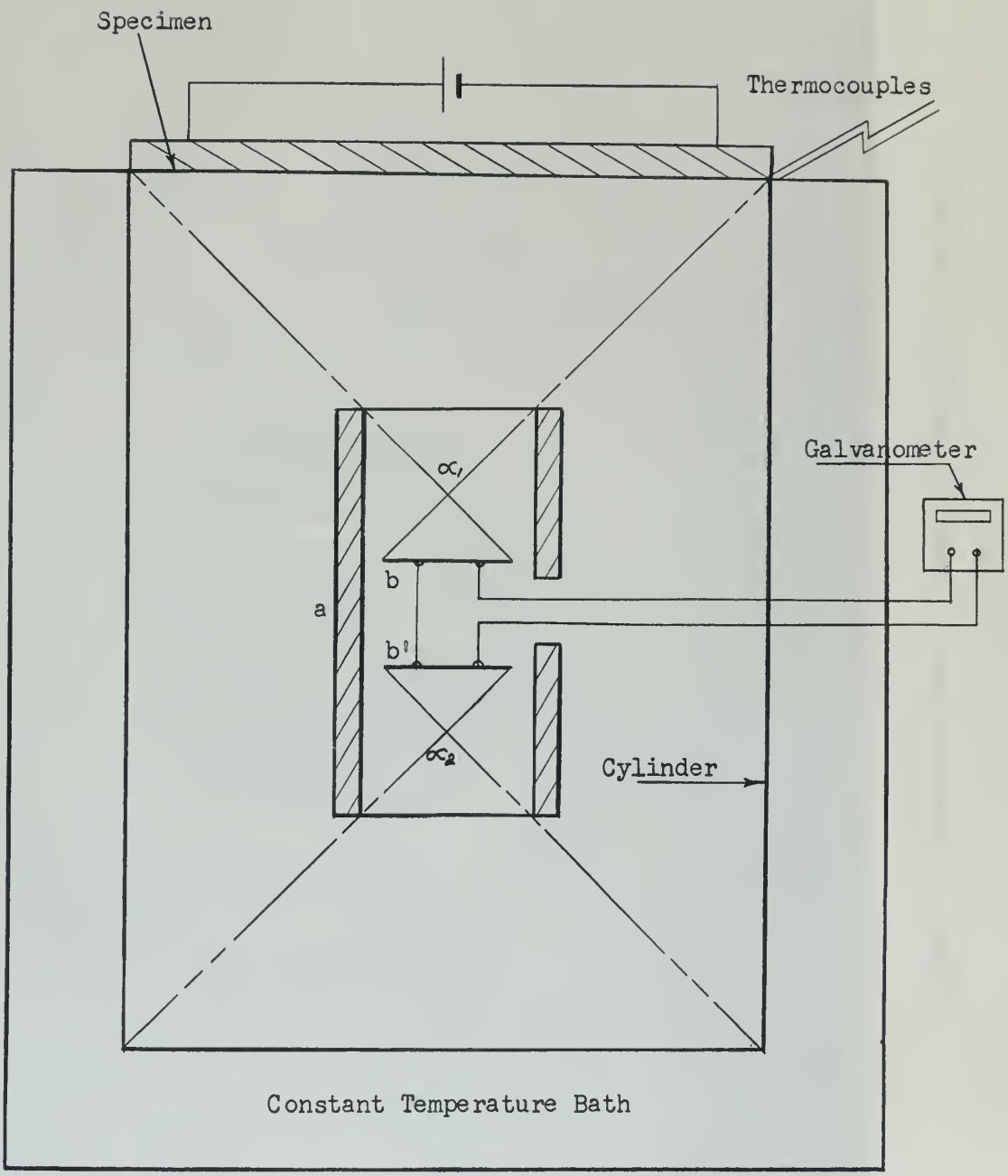


Figure 3. Kern's Apparatus for Measuring Emissivity

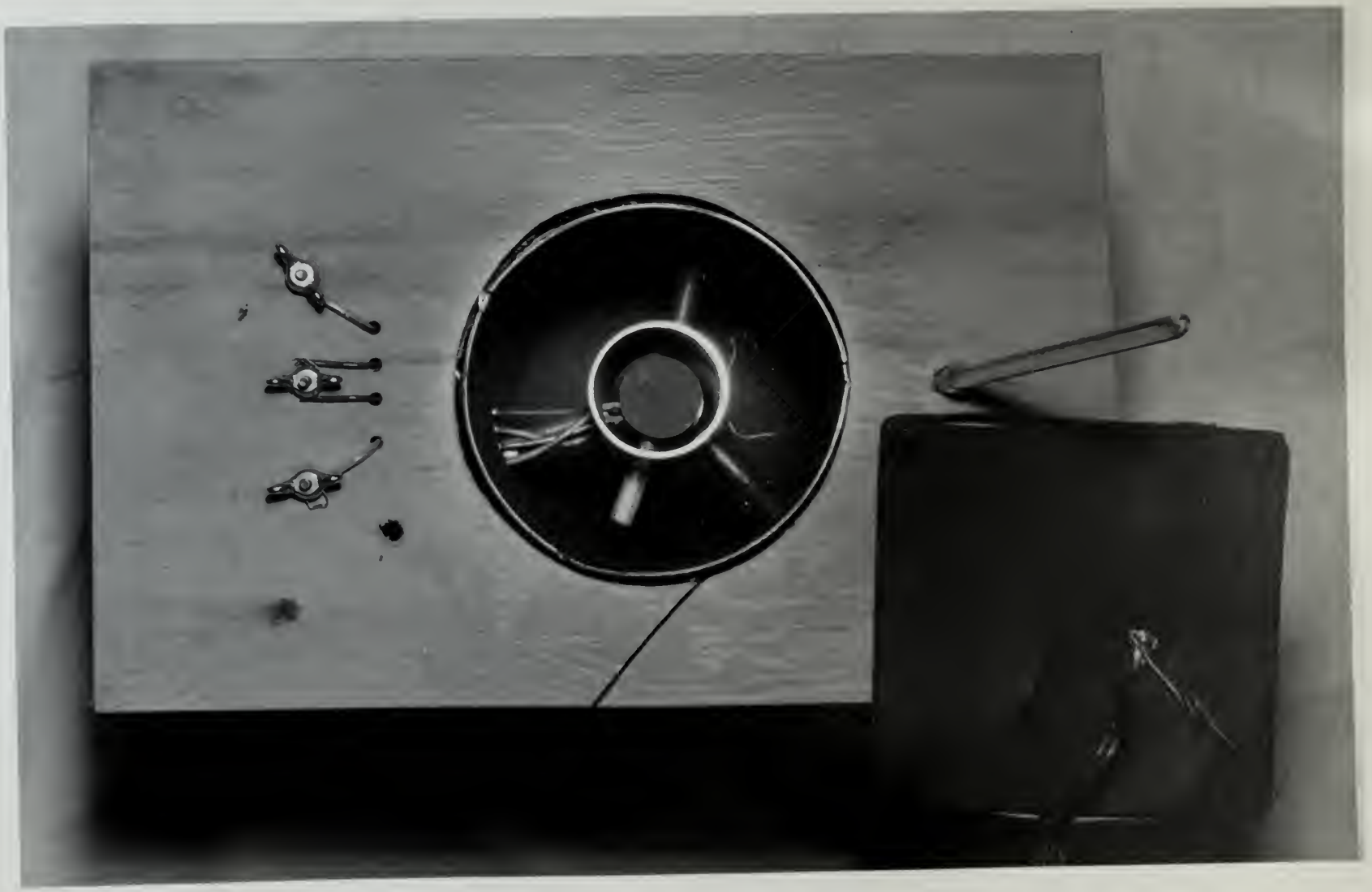


Figure 4. Instrument Used in Measuring Emissivity, Top View

The specimen fabrics were heated by a plate, lower right in Figure 4 and top center in Figure 5, which was constructed with a 1/8 inch aluminum plate backed with a nichrome wire heating element. The heating element was insulated electrically with asbestos paper and was backed with a one inch Pine block. The fabrics were glued to the plate and the thermocouple held against the fabric face by a spring. The thermocouple was covered, on the side not touching the fabric, with a thin polished copper shield designed to entrap the warm air between the shield and the thermocouple and also to reduce radiation influence on the thermocouple.

The entire list of equipment used in conjunction with the emissivity measuring device is as follows:

Rheostat, 7 ohms

Voltmeter, 1 - 10 volts, D.C., Simpson Model 29

Ammeter, 1 - 10 amps, D.C., Simpson Model 29

Wide mouth thermos constant-temperature bath

Leeds and Northrup Type K Potentiometer

Two 1.5 volt dry cells

Standard Cell, Eppley Laboratories

Double pole double throw knife switch

Galvanometer, Weston, Model 440, 1 division equals 2.2×10^{-6} amps, 3.7 ohms

Three ohm shunt for the galvanometer.

The voltmeter, ammeter and rheostat were connected in the heating element circuit and were used only as an aid in maintaining a constant specimen surface temperature. The galvanometer was connected through a

Figure 5. Apparatus Set Up for Measuring Emissivity

double-pole double-throw knife switch and served the dual purpose of determining the temperature of the fabric surface, and of indicating the potentiometer balance. When performing the latter function the galvanometer was not shunted. This entire system is shown in Figure 5.

Thermocouple Calibration.--All thermocouples were made with copper and constantan junctions. The junction points of both metals were cleaned with emery cloth and then firmly joined together by rolling the copper around the constantan and finally clamping in a vise. The open edges of the copper were then tinned with solder to prevent the entry of moisture into the junction.

Calibration was accomplished by placing one junction in a bath containing finely cracked ice. The other junction was then placed in a steam column directly over a beaker of boiling water. The steam column was blocked at the end with a wad of cotton. The E.M.F. generated by the couple was then checked with a potentiometer and the potentiometer reading compared with the standards provided by Leeds and Northrup.

Calibration of the galvanometer was accomplished by binding the thermocouple to the bulb of an accurate mercury thermometer and immersing the two in a series of baths at various temperatures. The galvanometer deflection for each known temperature was recorded and the results plotted on a graph, Figure 11.

CHAPTER IV

PRELIMINARY TESTS AND PROCEDURE

Characterization of the Sample Fabrics.—Fabric identification data was obtained by following standard procedures. The material was determined by microscopic examination and the weave was determined by picking out several repeats of the warp. The thickness, construction and weight were determined in accordance with the American Society for Testing Materials Standard D 39-49 (32). Densometer readings were obtained in accordance with the procedure outlined in Haven (33) and five determinations were made on both the untreated and metallized samples. Warp and filling yarn counts were determined by cutting a three inch square of each sample, weighing 36 picks and 36 ends, and computing the counts.

Preparation of the Samples.—A metal template 4 x 5 inches was cut from a steel plate. The fabrics were laid on a flat table and arranged so that they were neither wrinkled nor under tension. The metal template was then laid on top of the fabric and a razor blade used to cut out two specimens of each sample. One specimen of each sample was metallized. Each sample was then folded lengthwise so that the metallized, or corresponding side of the untreated sample, sides were facing each other. A sock was formed by sewing, on an ordinary sewing machine, two of the three open sides of the folded fabric. In all cases the stitching was along a line 3/16 of an inch from the cut edge. Socks of the same diameter for both untreated and metallized fabrics were thus formed.

Metallization.—A twenty centimeter length of aluminum wire, approximate weight 0.028 grams, was cut into 20 segments of one centimeter each. These segments were then bent into a V shape and hung near the center of the bell jar filament.

The fabric samples were suspended from a circular rack by means of bent pins which were designed to allow only a small portion of the point to project through the fabric. The circular rack was then placed on the evacuation table in such a manner that the fabrics were approximately parallel with the filament and so that no obstruction intervened between the filament and the sample. The gasket and bell jar were then set into place.

The mechanical vacuum pump was started and the valves opened so that the oil diffusion pump was out of the system. After the pressure dropped to approximately 10^{-2} mm of mercury, the oil diffusion pump was brought into the system. When the pressure in the system reached approximately 2×10^{-5} mm of mercury, the filament voltage was raised slowly until the aluminum pins were melted and had coated the filament. This always raised the pressure in the jar and evaporation would have to wait until the lower pressure was again attained. When the lower pressure was reached, the filament was energized with approximately 70 to 80 amperes for one to three seconds and evaporation of the aluminum was accomplished. The filament supply was immediately turned off and the vacuum system valves closed before stopping the pumps.

Determination of Cooling Times.—It was originally intended to perform the experiments by maintaining the cylinder at a constant temperature and then measuring the energy input. However, with the apparatus available, it was

found that at temperatures of zero and below it was almost impossible to achieve a rheostat setting which would result in a constant cylinder temperature. In addition to this, the freeze chamber, used for all determinations below freezing, was incapable of maintaining temperatures of sufficient consistency to make a constant input determination possible. After considerable experimentation it was found that reproducable results could be obtained by measuring the time involved for the cylinder to cool through a predetermined range of temperatures.

Samples number 1 through 8 were tested in a six cubic foot freezer chest. A fan was mounted in the freezer in such a way that there were no detectable air currents blowing on the cylinder. The power source, meters, rheostat and constant temperature thermos with chipped ice were located outside of the chest. The cylinder with the attached thermostat was placed inside the chest. Tests in this chest were made at -22.0°F, 0.0°F and at 20.0°F.

All sample socks were conditioned in the cold chamber for a period of 24 hours before being tested. The socks were placed on the cylinder by pulling the sock down until the closed end was drawn tightly over the end of the cylinder. The sock was then released and it returned slightly to a relaxed position. This precaution was taken so all samples would be fitted on to the cylinder in the same manner.

After the sample had been placed on the cylinder and the chest closed, the temperature of the cylinder was raised to a galvanometer deflection of 15, approximately 120°F., the power removed from the heating element, and the cylinder allowed to cool naturally. The cooling rate was timed between galvanometer readings 12 and 8, which corresponded to a

temperature drop between 97°F. and 84.2°F. Cooling curves for the cylinder without a sample were made and are illustrated in Figures 12 through 15 of the Appendix. It will be noted that straight line data plots are attained in the range of cylinder temperatures at which the fabrics were tested.

During the preliminary tests it was found necessary to take each sample sock through the heating and cooling cycle for a period of approximately 20 minutes before consistent readings could be obtained. This was particularly necessary in the case of cotton and viscose while the other fibers would produce constant results in a shorter time. Consequently each sample was cycled for 20 minutes before an actual timing run was made.

The refrigeration equipment was not capable of maintaining a constant temperature. Consequently, after the samples had been cycled, the thermostat controlling the refrigeration equipment was operated manually and runs were made only at the temperatures indicated in the data.

The procedure described above was followed for the final run made with this series of samples with the exception that a "walk in" type cooler was used rather than the freezer chest. All runs in this series were made at a temperature of 34°F.

Constant Cylinder Temperature Method.—After reviewing the results of changes in insulating value of the first eight samples, it was decided to test the next five fabrics at temperatures around 35°F. The walk in chamber used in this phase of the experiment was capable of maintaining temperatures constant within ± 1°F. With the equipment to be used it was noted that after a rheostat setting had been decided upon, the cylinder

would seek a constant temperature and then follow the cycling of the cold chamber temperature very accurately and with a lag of one minute. It was therefore possible to wait until the cold chamber attained a constant temperature for a period of two to three minutes and then take readings. In this series of runs, all of the meters and equipment including the storage battery were placed in the cold chamber. The thermometer used to record the chamber temperature was located three inches from the cylinder with the bulb at the same height as the thermocouple on the cylinder. The bulb of the thermometer was shielded with a piece of aluminum foil to prevent any radiant effects which might have been caused by the close proximity of the heated fabrics.

The first run was made without a sample sock on the cylinder. The rheostat was set and allowed 45 minutes to reach equilibrium. Three readings at approximately 15 minute intervals were taken at times when the cold chamber had maintained a constant temperature for a period of not less than two minutes. The readings consisted of the following:

Temperature of the cylinder

Temperature of the cold chamber

Heating element potential difference

Heating element current.

In the runs made with the sample fabrics, the socks were placed on the cylinder as described in the previous section, and the actual run was made as described above. During the course of any single run, if the voltage changed, the data was discarded and the run started again.

Determination of Emissivity.--After the apparatus for the determination of emissivity had been constructed it was tested with three materials the emissivity of which was known at a specified temperature.

Table 2. Comparison of Known Emissivities and Emissivities Obtained with the Apparatus Used in this Experiment

Material	Temperature Specified Degrees F.	Known Emissivity	Temperature Used in this Test Degrees F.	Calculated Emissivity
Polished Aluminum	100	0.04	100	0.09
Asbestos Paper	200	0.93	100	0.89
Sheet Steel Rough Oxide Layer	75	0.80	100	0.78

The values specified in the second and the third column of the table were obtained from Kern (34) and Wilkes (35).

It will be noted that the differences in the emissivities in the case of the polished aluminum is relatively high, however, on an absolute basis it is not considered to be prohibitive. This is especially true because the range of emissivities tested in these experiments was well above the value of polished aluminum. It is known that the emissivity decreases as the temperature decreases. The test results using asbestos paper and sheet steel with a rough oxide layer indicate satisfactory accuracy. While it was impossible to duplicate the results of other investigators, the results were sufficiently close, considering the variables involved, to permit the conclusion that the apparatus was functioning properly and would yield reasonable results provided the samples were of relatively high emissivity. It was also noted that when a black body

of the same type as that used on the can surface was placed at the top of the can and maintained at the same temperature as the constant-temperature bath, a zero potentiometer reading would result thus indicating that the internal discs were absorbing and emitting energy in equal amounts at constant and equal temperatures.

The constant-temperature bath was maintained at a temperature of 70°F. by virtue of the fact that the experiments were conducted in a laboratory which was conditioned at 70°F. and 65% R.H. The temperature of the bath was checked with an ordinary mercury thermometer during each run and no difficulty was experienced in maintaining the constant temperature.

During preliminary experiments with this apparatus it was found that after the specimen sample had been held at 110°F. for a period of approximately three to five minutes, a potentiometer reading could be obtained. Continuing to hold the sample at this temperature for an additional 15 minutes would not produce any change in the potentiometer reading. It was also noted that the potentiometer reading would be the same regardless of whether the 110° temperature was approached from the high or the low side.

The first step in the testing of the fabric samples was the careful removal of the stitching from each sock. The samples were then laid out and allowed to assume a flat position. The samples were attached to the heated plate by the use of rubber cement. The cement was applied to the plate and allowed to become tacky, at this point the samples were pressed firmly on to the plate. A clean cotton cloth was used in pressing the samples to the plate in order to protect the metallic surface and prevent

the surface from being contaminated with oil from the hand. The thermocouple was then placed on the fabric surface and held in place by the tension spring. The entire assembly was then placed over the top of the can and the heating element turned on. The fabric surface temperature was held at 110°F. for a period of from five to seven minutes. The potentiometer was balanced after five minutes and checked during the next two minutes. The reading was then recorded. This procedure was followed for all 13 untreated and metallized samples.

CHAPTER V

DISCUSSION OF RESULTS

Metallization.--Bonet-Maury investigated the evaporation of polonium from a point source and concluded that the condensation of the metal on a plane surface was proportional to the inverse square of the distance from the source, and to the cosine of the angle between the normal to the surface and the line connecting the surface with the source. It has been assumed that the same is true of other metals which have a low vapor pressure at room temperature (36). To find the thickness of the film at a specified distance from the point source it is considered that the metal molecules radiate uniformly in all directions and that if the point source were in the center of a sphere, a uniform deposit would result on the inside surface of the sphere. From these considerations it follows that

$$r_o = \frac{m}{4\pi\delta p^2} \tag{7}$$

where: r_o = the thickness of the evaporated film,

m = the mass of the metal being evaporated,

δ = the density of the metal being evaporated,

p^2 = distance from the source to the surface of the sphere (p T_o).

For the purposes of this work, only the maximum thickness of the metallic coating will be calculated because over the surface of the fabric samples the metal thickness will vary from this value to zero. The weight of the aluminum wire on the filament was 0.0285 grams and the sample

fabrics were approximately nine centimeters from the filament at the closest point. This would produce a film of approximately 1040 angstrom units in thickness.

The fabric surface geometry will greatly effect the presence or absence of metal due to the fact that "shadowing" will occur if the particular surface in question is not exposed to the source. The effect of the fabric geometry upon shadowing is shown in Figure 6. It would have been desireable in metallizing the fabrics used in this experiment to have utilized an extended array of source filaments so that shadowing would have been reduced.

Although no tests were made, it appears that metallic coating by chemical deposition, burning on, or gaseous deposition would have provided means of metallizing greater areas of the fiber. It appears that the straight line restrictions which govern vapor deposition would not be present in these methods.

No tests were made to determine the adhesion of the metal film to the fabric. However, during the experiments it was noticed that some of the aluminum had rubbed off on the electrical tape at the base of the test cylinder. The electrical tape is relatively smooth and the socks were not deliberately rubbed against the tape. The indication would therefore be that the film was not adhering with any great degree of tenacity. On the other hand, the nylon and dacron samples could be rubbed quite vigorously with the thumb without any visible wear.

Due to the extreme thinness of the films on the fabrics and the fact that aluminum is inherently a relatively soft metal, it was decided that none of the standard abrasion tests would produce any worthwhile results.

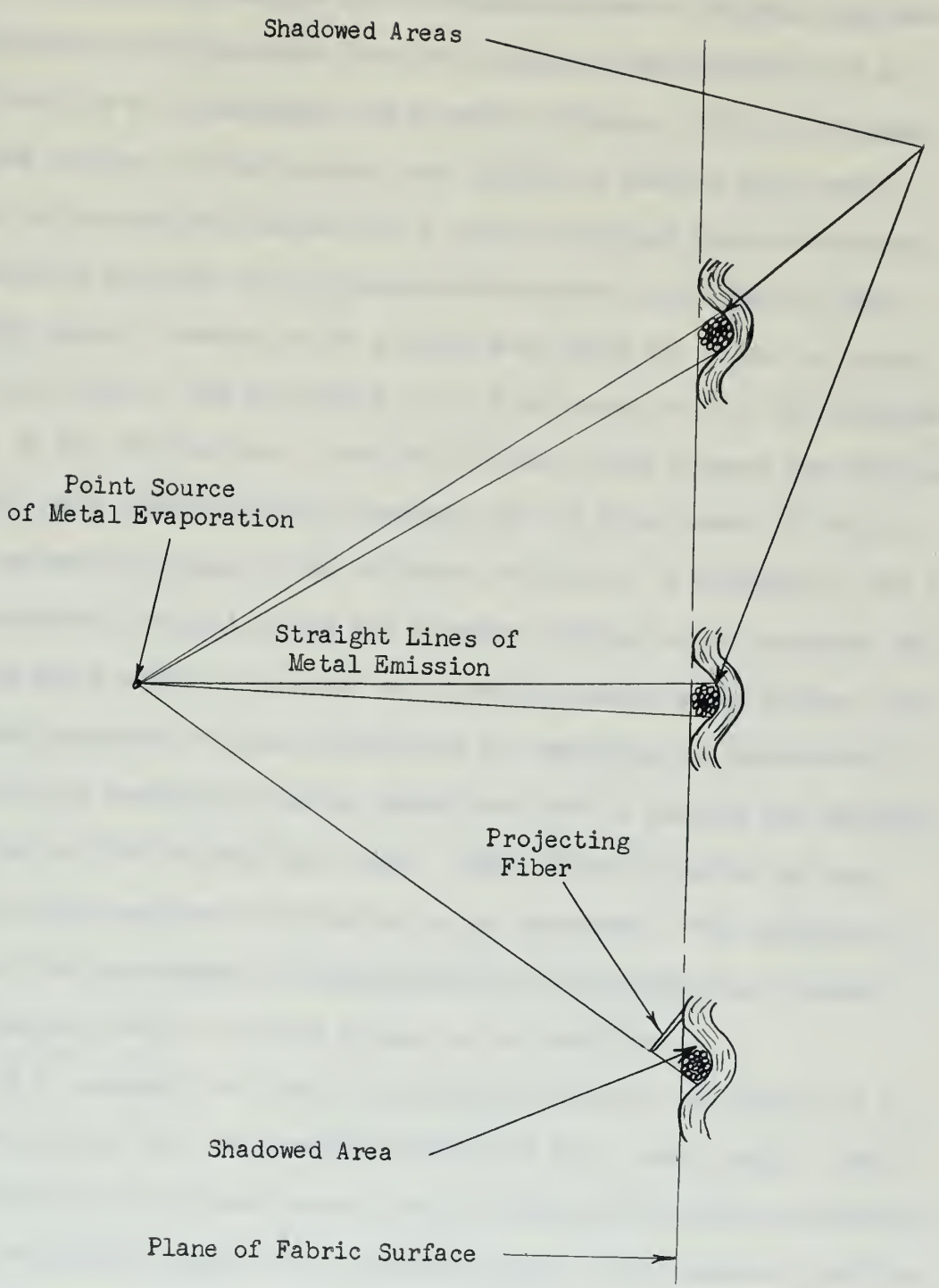


Figure 6. Shadowing Effect on an Irregular Surface From a Point Source of Metal Evaporation

All of the samples were chemically clean at the time they were metallized. This fact alone does not suffice in the deposition of a metallic film to a substrate. In a report by Belser (37), it is shown why this is true. After cleaning and flaming, a surface will remain coated or be rapidly recoated with a layer or several layers of adsorbed gas which is believed to be preponderantly water vapor. Part of this adsorbed gas will remain on the surface even after the object is placed in a high vacuum. The hypothesis is that the metallic film is deposited on top of the adsorbed gas. The Van der Waal forces between two different materials are reported to vary inversely as the sixth power of the distance between the atoms of the different materials. A distance of ten or more angstroms occupied by the gas or water molecule would eliminate any adhesion which could be expected as a result of solid-solid forces. Experiments performed on glass substrates and employing ion bombardment of the substrate immediately before deposition tend to confirm the existence and effect of the adsorbed gas layer. Metal films deposited by this procedure show much better adhesion to the substrate. The inference is that the ion bombardment had removed some of the adsorbed gas thereby permitting the metal to settle closer to the substrate.

It is assumed that textile materials would also be bounded by an adsorbed gas and that the condition described above would apply. While no adhesion tests were performed in this research, this facet of metallization is of primary importance if durable films of good adhesive qualities are to be produced.

Calculations.--The rate of cooling method of determining the insulation values of fabrics is not a preferred method of making such determinations.

It does however, serve as a useful method for making comparisons between different fabrics. The total amount of heat transferred through a fabric is the sum of the heat transferred by conduction, convection and radiation. A review of equations (1), (2) and (3) will reveal that in the rate of cooling method all functions in these equations remain constant with the sole exception of the time, and each equation resolves into the following form.

$$H = k \times t \tag{8}$$

where H = the quantity of heat transferred

k = constant

t = time

When expanding this to encompass all three modes of heat transfer the equation becomes,

$$H_{total} = (t \times k_{rad}) + (t \times k_{conv}) + (t \times k_{cond}) \tag{9}$$

or:

$$H_{total} = t\,(k_{rad} + k_{conv} + k_{cond}) \tag{10}$$

which resolves into:

$$H_{total} = t \times K \tag{11}$$

Since the quantity of heat is the same for every run, the time, t, will be inversely proportional to the conductance K. Conversely, the time will be directly proportional to the insulating value.

The Thermal Insulating Value, referred to as T.I.V. in tables, as previously described is a percentage. As such, it is possible to insert

the cooling times directly into the T.I.V. equation. Calculating the percent increase in T.I.V. the equation resolves as follows:

$$\% \text{ Increase in T.I.V.} = \frac{\dfrac{(t_o - t_{cm})}{t_o} \quad \dfrac{(t_o \quad t_{cu})}{t_o}}{\dfrac{(t_o - t_{cu})}{t_o}} \tag{12}$$

or:

$$\% \text{ Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \tag{13}$$

where: t_o = Seconds required to cool the cylinder without a sample

t_{cu} = Seconds required to cool the cylinder with an untreated sample

t_{cm} = Seconds required to cool the cylinder with a metallized sample

The method used to compute the Thermal Insulating Value of the samples in the constant cylinder temperature runs is more direct. In this case the heat transferred through the fabric is taken as

$$k = \frac{E \times I}{252 \times 4.158 \times (T_2 - T_1)} \tag{14}$$

Where: E = heating element potential difference in volts

I = heating element current in amperes

T_2 = temperature of the cylinder in degrees F.

T_1 = temperature of the cold chamber in degrees F.

4.158 is the number of jouls per calorie

252 is the number of calories per Btu

K = Btus per sec per °F.

Btus were used as the unit of heat only because temperatures had been recorded in °F. and it was decided to carry through with the British system.

Effect of the Fabric Surface on the Increase in Thermal Insulating Value.--The first eight fabrics selected for this thesis were chosen because of the different surface characteristics presented by each. The nylon and orlon samples are essentially the same with the exception that the nylon fiber has a circular cross section while the orlon has an irregular cross section. Dacron is also a circular fiber however the other parameters of fabric character differed from the first two samples. Three samples of viscose were used. One sample was a filament fabric and the other two were of staple yarns. In the case of these viscose fabrics the weave and construction characteristics vary markedly. Cotton broadcloth, of a high quality, was used and its characteristics differed from all others tested. The Dynel honeycomb fabric was chosen in the hope that the deep depressions in the fabric would provide a greater air space and provide a greater insulation value. This fabric, however was of such a loose construction that the fibers were only partially metallized and the shadowing effects were more pronounced than in the case of the other fabrics. The results of the tests with this fabric are recorded but because of the obvious defficiencies they are not used for comparative purposes. The characteristics of the fabrics tested are shown in Table 3.

The change in emissivities caused by metallization is probably the best method by which to compare the effect of the surface on the increased insulating value. In the first series of tests the emissivities of the metallized samples ranged from 0.55 to 0.84, from which the obvious

Table Number 3. Characteristics of the Fabrics Used in These Experiments

Sample Number	Material	Weave	Thickness (inches)	Construction	Warp	Filling	Weight (oz/yd^2)	Yarn Type	Densometer Reading (seconds)
1	Nylon	Twill	0.004	125x80	74/34	80/34	1.20	Filament	7.5
2	Orlon	Twill	0.004	125x80	74/34	80/34	1.11	Filament	8.5
3	Dacron	Plain	0.004	130x60	77/34	80/34	1.73	Filament	5.8
4	Viscose	Plain	0.009	170x150	100/35	100/35	3.44	Filament	17.4
5	Cotton	Plain	0.015	148x58	80s/2	50s/2	3.55	Staple	16.4
6	Dynel	Honeycomb	0.050	135x72	20s	20s	9.64	Staple	4.5
7	Viscose	Plain	0.025	42x42	6s	6s	8.81	Staple	10.1
8	Viscose	Twill	0.020	134x84	18s	18s	8.68	Staple	19.5
9	Nylon	Basket	0.014	120x80	210/34	210/34	5.75	Filament	175
10	Nylon	Satin	0.013	120x80	210/34	210/34	5.60	Filament	52
11	Nylon	Basket	0.015	97x60	260/17	260/17	5.78	Filament	46
12	Nylon	Basket	0.014	97x60	260/17	260/17	5.61	Filament	29.1
13	Nylon	Satin	0.016	97x65	260/17	260/17	6.13	Filament	16.3

implication could be drawn that the fabric with the lowest emissivity would yield the largest percentage increase in insulating value. This conclusion was born out in actual tests for the percentage increase in Thermal Insulating Value as shown in Table 3.

Table 4. Comparison of Emissivities of the Metallized Samples and the Percent Increase in T.I.V. of the Metallized over the Untreated Samples

Sample Number	Emissivity	Percent Increase in T.I.V.
1	0.55	15.9
2	0.60	12.7
3	0.61	7.7
4	0.67	7.6
5	0.71	5.2
6	0.75	5.3
7	0.83	3.6
8	0.84	0.5

In view of the fact that shadowing undoubtedly played a part in differences in the emissivities the results shown above can be considered valid only for fabrics metallized by evaporation from a semi-point source.

It will be noted that the four fabrics with the lowest emissivities and the greatest increase in T.I.V. are all filament fabrics. This could have arisen from the fact that these fabrics had no projecting fibers or it could have been due to the fact that the filament yarns have very little twist and therefore produce a yarn with a more uniform surface than do the yarns made of staple fibers. Then too, the effect of construction, weave, fiber denier and fibers per cross section of yarn may also be significant.

The second phase of this thesis was undertaken in an attempt to determine the effect of the weave on the emissivity and the percent increase in T.I.V. The fabrics made of nylon were chosen only because they were available in filament form, because the nylon fiber is circular, and it was this type of fabric which had produced the most promising results in the first phase.

The first two samples in this series, samples number 9 and 10 are the same except for the weave. Samples number 11, 12 and 13 are the same except for the weave, and sample 13 is of a slightly tighter construction. The results of the tests on the first of these samples shows no significant change in either emissivity or increase in T.I.V. which could be attributed to the weave differences. Of the last three samples tested, sample number 12 showed a marked decrease in the emissivity and an increase in the percent increase in T.I.V.

Table 5. Comparison of the Emissivities of the Metallized Samples Number 9 through 13 and the Percent Increase in T.I.V. of the Metallized Over the Untreated Fabrics

Sample Number	Emissivity	Percent Increase in T.I.V.
9	0.56	13.2
10	0.55	15.3
11	0.55	14.4
12	0.41	28.6
13	0.59	12.5

Sample number 12 was a 4 x 4 basket weave and had longer floats than any of the other samples. It would seem that these longer floats presented a

smoother, more uniform surface which in turn would account for the significant difference between it and the other metallized samples.

Discussion of Photomicrographs.--Photomicrographs of the fabric with the highest emissivity and the fabric with the lowest emissivity are shown in Figures 7 and 8 respectively. Figure 7 is the 4 x 4 basket weave and Figure 8 is the viscose twill. The magnification of each micrograph is approximately 150X and because of the limitations in the depth of focus of the camera, only the fibers on or near the surface are clearly distinguishable.

Figure 7 shows the relative uniformity of the metallic film which was deposited on the individual fibers. It also shows a high degree of orientation among the many fibers which make up this section, which is one half of one repeat. It is believed that the transverse striations which are clearly visible on almost all of the fibers is the result of cracks in the metallic surface caused by flexing of the fabric. Examinations of the same repeat on the other side of the fabric, under a stereo microscope, revealed no such striations.

A comparison between Figures 7 and 8 will immediately reveal the difference in the fabric surface uniformity and how that difference effected the deposition of metal. Figure 8 shows the projecting fibers, the irregularities caused by the twisted yarn and the many areas which had been shadowed. Examination of this sample under the stereo microscope revealed that the metal had deposited in some areas, which in the micrograph show as grey areas between the surface yarns.

Figure 7. Photomicrograph of Sample Number 12 after Metallization, 150X

Figure 8. Photomicrograph of Sample Number 8 after Metallization, 150X

Effect of Cold Chamber Temperature on the Increase in Insulating Value of Metallized Fabrics.--At the outset of this thesis it was expected that the temperature of the cold chamber would effect the insulating value of the metallized fabrics. It was for that reason that the first eight samples were tested at different temperatures. After the results of the first phase of the tests were known, an analysis of variance and significance tests was run using the quality control methods described by Duncan (38). While these tests confirmed that there was a statistically significant difference between the fabrics at the different temperatures, it will be noted from Table 5 that no trend is established. It would not be proper to state that the temperature of the cold chamber was not significant, however, it is probable that the variations in evidence in Table 6 are the result of a lack of sensitivity in the equipment that was used, or that experimental error has concealed any trends.

Comparison of the Change in Emissivity and the Change in Thermal Insulating Value.--Two graphs of emissivity vs percent increase in Thermal Insulating Value were plotted and appear as Figures 9 and 10. In Figure 9, only those fabrics which had approximately the same insulating value before metallization were plotted. Figure 10 is for fabric samples 9 through 13. While it is realized that many additional points would have been valuable, it is felt that sufficient points are available to indicate a trend. In both Figures there is a relatively steep slope present in the emissivity range of 0.70 to 0.40. It appears that if the slope did not decrease, or decreased only slightly, large percentage increases in

Table 6. Summary of Percent Increase in Thermal Insulating Value as Computed in Tables 7 through 14

Sample Number	Percent Increase in T.I.V. at -22°F.	Percent Increase in T.I.V. at 0.0°F.	Percent Increase in T.I.V. at 20°F.	Percent Increase in T.I.V. at 34°F.	Average Percent Increase in T.I.V.
1	16.6	16.2	14.8	16.0	15.9
2	15.8	10.7	11.3	13.1	12.7
3	9.1	7.5	6.7	7.6	7.7
4	9.7	5.2	7.2	8.2	7.6
5	5.0	5.2	5.1	5.6	5.2
6	5.4	4.9	4.9	5.8	5.3
7	3.5	4.7	3.0	3.5	3.6
8	1.1	.6	.3	.2	.5

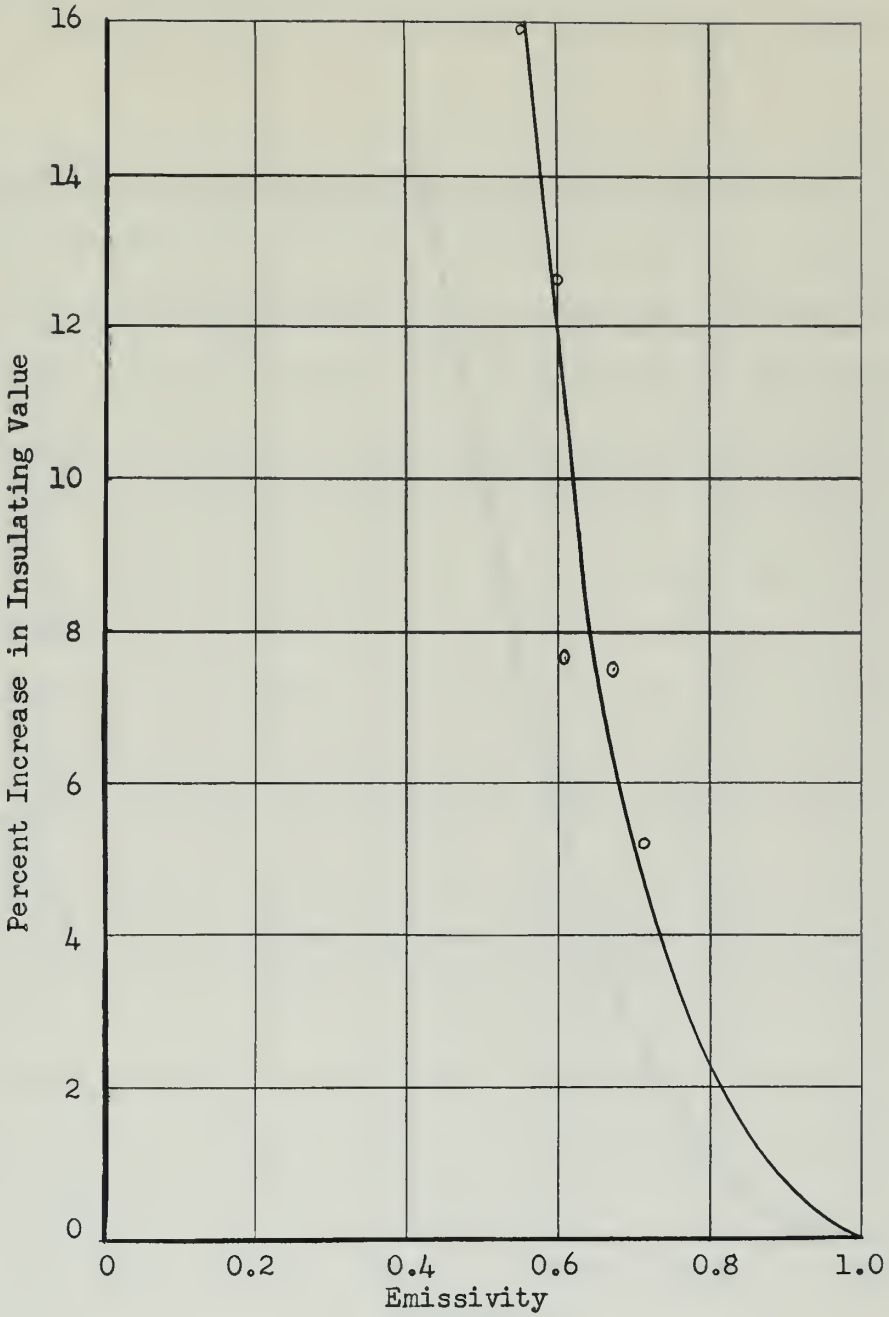
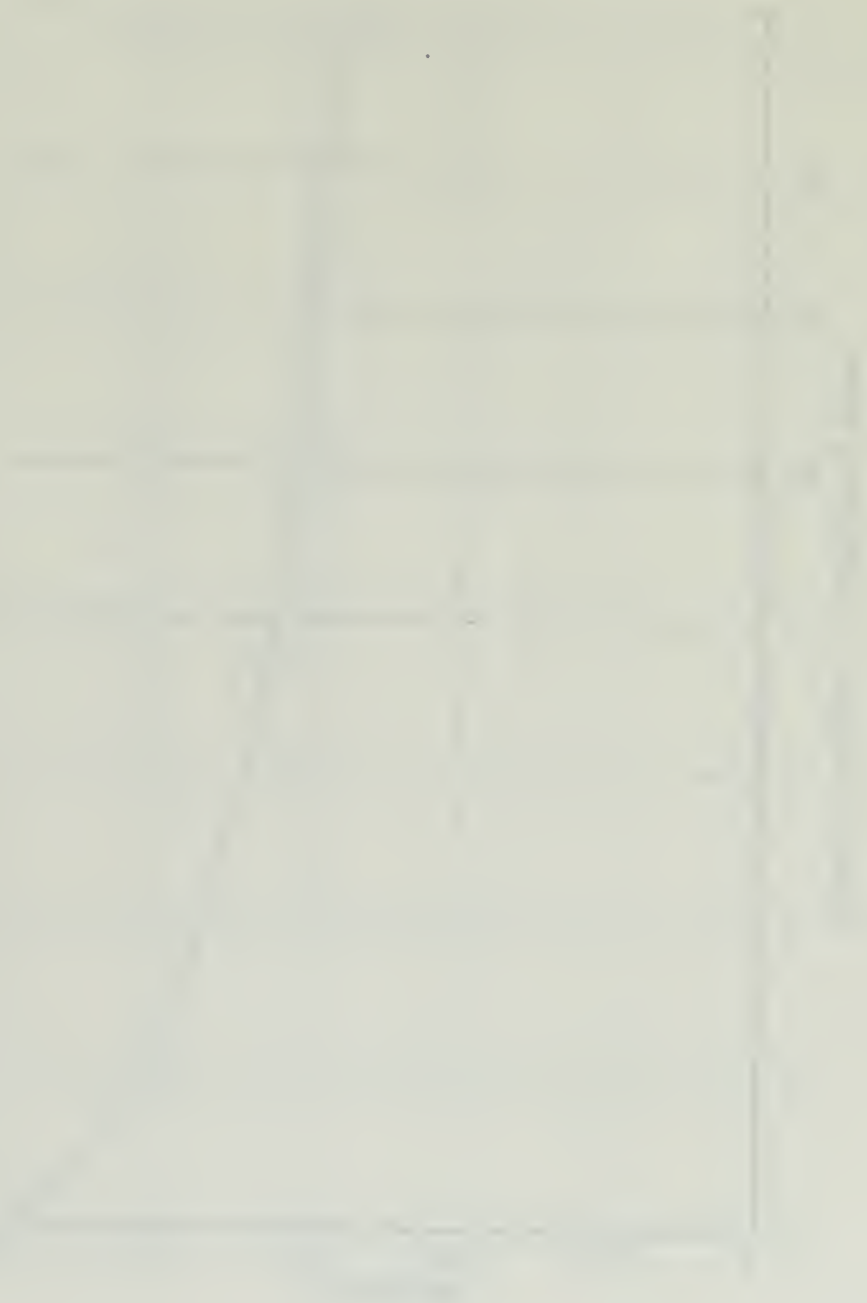


Figure 9. Emissivity vs. Percent Increase in Insulating Value for Samples Number 1 thru 5



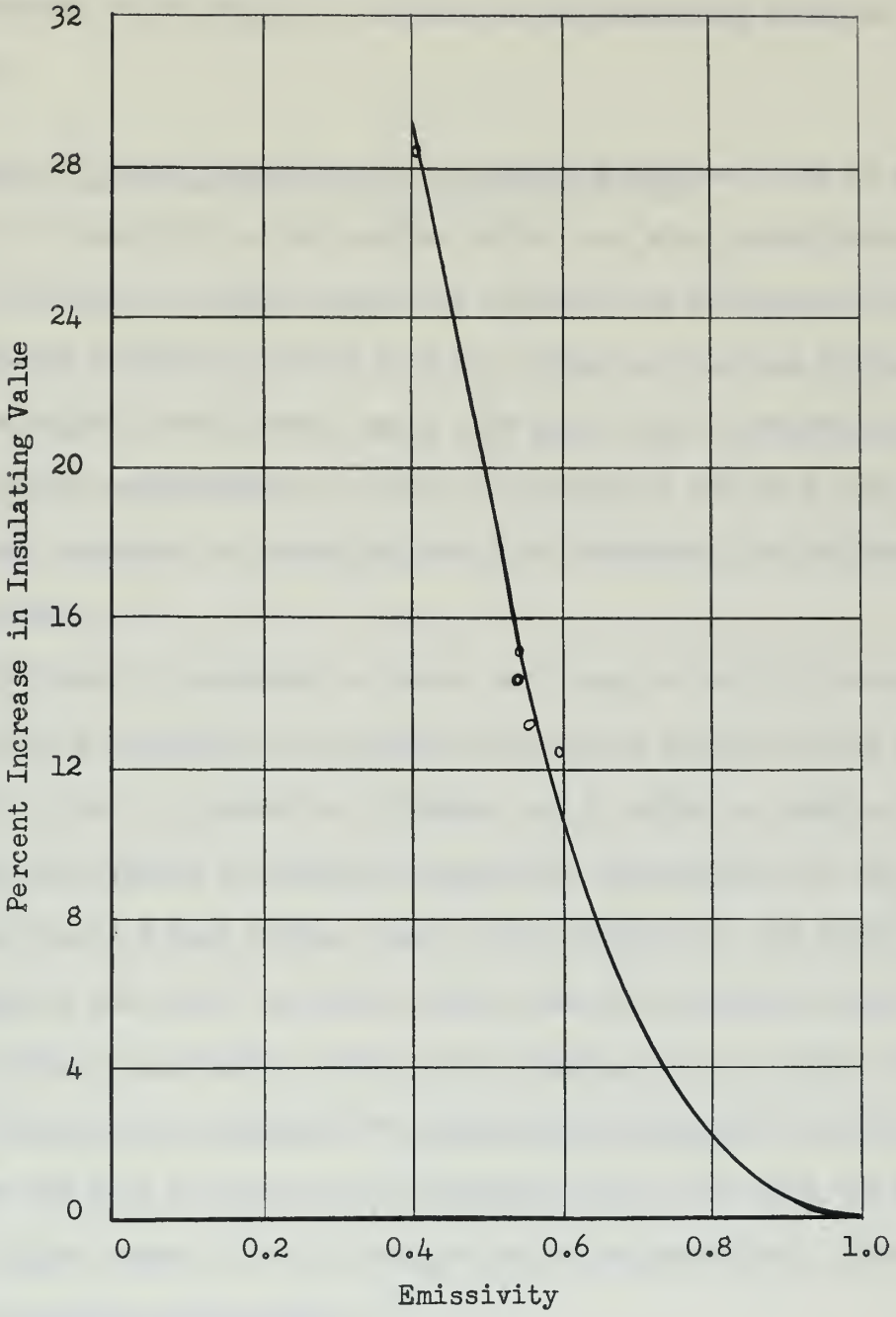


Figure 10. Emissivity vs. Percent Increase in Insulating Value for Samples Number 9 thru 13

the insulating value would be realized in the emissivity range of 0.10 and less.

The Effect of Vacuum Deposition on the Fabric Weight.—It was an early intention to weigh all of the samples before and after metallization, and from the increase in weight compute or estimate the thickness of the metal film. It was immediately noted that the cotton and viscose fabrics showed a loss in weight rather than a gain. The gross loss in weight was very slight, in the neighborhood of 0.5%, and in view of the fact that another method was available for computing the film thickness, the weighing method was discarded.

In trying to determine a reason as to why the weight decreased, two rather obvious thoughts were espoused; first, the metal vapor is at a high temperature when it leaves the filament, and it would be possible that the hot metal was causing a localized destructive distillation of the cellulose; second, in a high vacuum, some of the moisture in the fiber may have been removed, and after the metal surface had been deposited there would be areas where the moisture could not be regained by the fiber in the limited time before weighing. The second reason appears to be the more valid one and this conclusion is reinforced by the fact that the hydrophyllic fibers showed a loss in weight while the hydrophobic fibers showed a gain in weight after coating.

CHAPTER VI

CONCLUSIONS

The conclusions drawn from the results of these experiments can apply only to fabrics which have been metallized by evaporation from a point or small linear source. It is known that the shadowing effect was present, however, the importance of shadowing was not determined.

The results of these experiments show that fabrics can be metallized by the vacuum deposition process and that increases in the insulating value of a fabric up to 28% can be realized. The fabric surface has a marked effect upon the emissivity and the increase in the insulating value of a fabric as the rougher fabrics present a surface which is a greater departure from a plane surface. This study indicates that fabrics with a very low emissivity could substantially aid in conserving body heat.

In view of the fact that more fabrics, identical except for weave, were not tested; it is difficult to come to any firm conclusion concerning this parameter of fabric characteristic. The fact that one fabric did produce an increase in insulating value considerably above the others indicates that the weave is significant.

CHAPTER VII

RECOMMENDATIONS

None of the fabrics used in these experiments came close to having emissivities in the region of 0.1 or below, however, there are metallized fabrics available commercially which do approach this value. It would therefore seem advisable to continue the search for technically improved low emissivity fabrics.

In clothing applications where porosity is not an important consideration, metallized plastic sheets or films could be incorporated into sandwich structures and it appears that excellent insulating qualities would result. An investigation would appear to be warranted.

All of the several methods of thin metal film deposition should be studied with a view toward their usefulness in textile applications. Of particular interest would be the metals which can be deposited and the adhesion of the metal to the substrate. A study of the adhesive properties might well be considered to be of primary importance for it is upon this characteristic that the usefulness of thin metal films on textiles will finally hinge.

BIBLIOGRAPHY

LITERATURE CITED

1. The Encyclopedia Americana, New York, New York: Americana Corporation, 1954 Edition, Volume 29, p. 142.

2. Kaswell, Ernest R., Textile Fibers, Yarns and Fabrics, New York: Reinhold Publishing Corporation, 1953, p. 201.

3. Fourt, Lyman; Harris, Milton: Physical Properties of Clothing Fabrics, p. 303: L. H. Newburghs, Physiology of Heat Regulation and the Science of Clothing, Philadelphia, Pa., W. B. Saunders Company, 1949.

4. Herrington, L. P., "Clothing From a Biophysical Point of View", Papers of the American Association of Textile Technologists, Vol. 7, December 1951, p. 30.

5. Wilkes, Gordon B., Heat Insulation, New York: John Wiley and Son, 1950, p. 109.

6. Strong, John, Procedures in Experimental Physics, New York: Prentice-Hall, Inc., 1939, p. 151.

7. Ibid., p. 152.

8. Ibid., p. 159.

9. Ibid., p. 168.

10. Campbell, I. E., Powell, C. F., "Vapor Deposition May Solve Todays Coating Problems," The Iron Age, 169, (April 10, 1952), p. 113.

11. Powell, C. F., Campbell, I. E., "The Formation of Refractory Coatings by Vapor Deposition Processes", Journal of Chemical Education, 29 (April 1952) p. 181.

12. Bazett, H. C., The Regulation of Body Temperatures, p. 109: L. H. Newburgh, Physiology of Heat Regulation and the Science of Clothing, Philadelphia, Pa., W. B. Saunders Company, 1949.

13. Ibid., p. 150.

14. Hardy, J. D., Heat Transfer, p. 95: L. H. Newburgh, Physiology of Heat Regulation and the Science of Clothing, Philadelphia, Pa., W. B. Saunders Company, 1949.

15. Kern, Donald Q., Process Heat Transfer, New York, McGraw-Hill Book Company, 1950, p. 63.

16. Marsh, M. C., "The Thermal Insulating Properties of Fabrics", Journal of the Textile Institute, 22, (May 1931) p. T245.

17. Baxter, S., Cassie, A. B. D., "Thermal Insulating Properties of Clothing", Journal of the Textile Institute, 34 (July 1943) p. T41.

18. Rees, W. H., "The Protective Value of Clothing", Journal of the Textile Institute, 37, (July 1946) p. T132.

19. Gagge, A. P., Burton, A. C., Bazett, H. C., "A Practical System of Units For the Description of the Heat Exchange of Man with His Environment", Science, 94, (November 7, 1941) p. 428

20. Baxter, Cassie, op. cit., pp. T41-T54.

21. Fredman, E., "Thermal Transmission of Fabrics", Textile World, 78 (July 5, 1930) pp. 58-59.

22. Cook, K. B., "Warmth and Wearing Qualities of Spun Rayon and Wool Blended Fabrics", Textile World, 92, No. 9 (September 1942) pp. 113-114.

23. Rees, W. H., "Transmission of Heat Through Textile Fabrics", Journal of the Textile Institute, 32 (August, 1941) pp. T149-T166.

24. Morris, G. J., "Thermal Properties of Textile Materials", Journal of the Textile Institute, 44 (October 1953) p. T456.

25. Marsh, op. cit., p. T269.

26. Cassie, A. B. D., "Characteristics for Warmth in Underwear Fabrics", Journal of the Textile Institute, 40 (May 1949) p. P444.

27. Hardy, op. cit., p. 82.

28. Taylor, C. S., Edwards, J. D., "Some Reflection and Radiation Characteristics of Aluminum", Transactions of the American Society of Heating and Ventilating Engineers, 45 (1939) p. 179.

29. Fourt, Harris, op. cit., p. 302.

30. Staff Article, "Aluminized Safety Clothing Keeps Cool in Hot Jobs", Steel, 134 (June 14, 1954) pp. 118-121.

31. Kern, op. cit., p. 69.

32. A.S.T.M. Committee D-13 on Textile Materials, A.S.T.M. Standards on Textile Materials, Philadelphia: American Society for Testing Materials, 1951, pp. 138-141.

33. Haven, George B., Handbook of Industrial Fabrics, New York, Wellington Sears Company, Fourth Edition, 1949, p. 354.

34. Kern, op. cit., p. 71-72.

35. Wilkes, op. cit., p. 190.

36. Strong, op. cit., p. 177.

37. Belser, R. B., "Aging Study of Metals Plating on Quartz Crystals", Report No. 7, Army Project: 3-24-02-020, Signal Corps Project: 33-862-A, Atlanta: Engineering Experiment Station of the Georgia Institute of Technology, 1954, pp. 27-30.

38. Duncan, A. J., Quality Control and Industrial Statistics, New York: Richard D. Irwin, Inc., 1952, pp. 454-459.

OTHER REFERENCES

Hardy, H. B., Ballou, J. W., Wetmore, O. C., "The Prediction of Equilibrium Thermal Comfort from Physical Data on Fabrics", Textile Research Journal, 23 (January 1953) pp. 1-10.

Andreen, J. H., Gibson, H. W., Wetmore, O. C., "Fabric Evaluation Based on Physiological Measurements of Comfort", Textile Research Journal, 23 (January 1953) pp. 11-22.

Winston, G., Backer, S., "Measurements of the Thermal Transmission of Textile Fabrics", Textile Series - Report Number 39, Office of the Quartermaster General, Research and Development Branch, Department of the Army, June 1, 1948, Department of Commerce, Washington, D. C.

APPENDIX

Table 7. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	1
Material	Nylon
Weave	Twill
Thickness	0.004 Inches
Densometer	7.5 Seconds
Construction	125 x 80
Yarn Type	Filament
Warp	74/34
Filling	80/34
Weight	1.20 oz/yd^2

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	87.05	88.22	16.6
0.0	94.0	114.13	117.40	16.2
20.0	112.23	152.40	158.33	14.8
34.0	135.35	187.03	195.28	16.0

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 8. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	2
Material	Orlon
Weave	Twill
Thickness	0.004
Construction	125 x 80
Warp	74/34
Filling	80/34
Weight	1.11 oz/yd^2
Yarn Type	Filament
Densometer	8.5 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	86.02	86.97	15.8
0.0	94.0	111.48	113.35	10.7
20.0	112.23	151.28	155.68	11.3
34.0	135.35	185.93	192.55	13.1

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 9. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	3
Material	Dacron
Weave	Plain
Thickness	0.004
Construction	130 x 60
Warp	77/34
Filling	80/34
Weight	1.73 oz/yd^2
Yarn Type	Filament
Densometer	5.8 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	89.47	90.33	9.1
0.0	94.0	110.28	111.50	7.5
20.0	112.23	153.00	155.75	6.7
34.0	135.35	187.28	191.23	7.6

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computations:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 10. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	4
Material	Viscose
Weave	Plain
Thickness	0.009
Construction	170 x 150
Warp	100/35
Filling	100/35
Weight	3.44 oz/yd^2
Yarn Type	Filament
Densometer	17.4 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	90.3	91.3	9.7
0.0	94.0	111.40	112.30	5.2
20.0	112.23	153.33	156.30	7.2
34.0	135.35	187.03	191.28	8.2

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 11. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	5
Material	Cotton Braodcloth
Weave	Plain
Thickness	0.015
Construction	148 x 58
Warp	80s/2
Filling	50s/2
Weight	3.55 oz/yd^2
Yarn Type	Staple 1 inch
Densometer	16.4 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	93.33	94.00	5.0
0.0	94.0	113.20	114.20	5.2
20.0	112.23	155.30	157.50	5.1
34.0	135.35	189.85	192.88	5.6

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 12. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	6
Material	Dynel
Weave	Honeycomb
Thickness	0.050
Construction	135 x 72
Warp	20s
Filling	20s
Weight	9.64 oz/yd^2
Yarn Type	Staple
Densometer	4.5 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	122.60	124.90	5.4
0.0	94.0	135.48	135.50	4.9
20.0	112.23	201.95	206.38	4.9
34.0	135.35	249.05	255.65	5.8

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 13. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	7
Material	Viscose
Weave	Plain
Thickness	0.025
Construction	42 x 42
Warp	6s
Filling	5s
Weight	8.81 oz/yd^2
Yarn Type	Staple
Densometer	10.1 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	94.08	94.57	3.5
0.0	94.0	115.28	116.20	4.7
20.0	112.23	157.15	158.50	3.0
34.0	135.35	196.55	198.70	3.5

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 14. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabric

Sample Number	8
Material	Viscose
Weave	Twill
Thickness	0.020
Construction	134 x 84
Warp	18s
Filling	18s
Weight	8.68 oz/yd^2
Yarn Type	Staple
Densometer	19.5 Seconds

Temp. of Cold Chamber Degrees F.	Uncovered Cylinder Cooling Time Seconds (t_o)	Cylinder Cooling Time with Untreated Sample Seconds (t_{cu})	Cylinder Cooling Time with Metallized Sample Seconds (t_{cm})	Percent Increase in Thermal Insulating Value
-22.0	80.0	95.82	96.0	1.1
0.0	94.0	114.95	115.08	.6
20.0	112.23	158.55	158.68	.3
34.0	135.35	195.00	195.13	.2

The cooling times listed in the above table are the number of seconds required to cool the cylinder from 97.0°F. to 84.2°F.

All of the above data represents the average of four readings.

Summary of computations:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Table 15. Energy Required to Maintain a Constant Cylinder Temperature with Untreated and with Metallized Samples

Sample Number	9
Material	Nylon
Weave	2 x 2 Basket
Thickness	0.014 Inches
Construction	120 x 80
Warp	210/34
Filling	210/34
Weight	5.75 oz/yd^2
Yarn Type	Filament
Densometer	175 Seconds

Sample	Temperature of Cylinder Degrees F. (T_c)	Heating Element Volts (E)	Heating Element Amperes (I)	Temperature of Cold Chamber Degrees F. (T_i)	Btu/second/ Degree F. x 10^{-5} (H)
Untreated	99.2	2.85	1.07	33.0	4.36
Metallized	100.8	2.85	1.07	32.2	4.21

All of the above data represents the average of three readings taken at 15 minute intervals after the sample has been on the cylinder for a period of 45 minutes.

Summary of computation:

$$H = \frac{E \times I}{4.158 \times 252 \times (T_c - T_i)} \qquad (14)$$

Table 16. Energy Required to Maintain a Constant Cylinder Temperature with Untreated and with Metallized Samples

Sample Number	10
Material	Nylon
Weave	5 Harness Satin
Thickness	0.013 inches
Construction	120 x 80
Warp	210/34
Filling	210/34
Weight	5.60 oz/yd^2
Yarn Type	Filament
Densometer	52 Seconds

Sample	Temperature of Cylinder Degrees F. (T_c)	Heating Element Volts (E)	Heating Element Amperes (I)	Temperature of Cold Chamber Degrees F. (T_i)	Btu/second/ Degree F. x 10^{-5} (H)
Untreated	100.2	2.83	1.05	36.0	4.39
Metallized	101.3	2.80	1.04	36.0	4.23

All of the above data represents the average of three readings taken at 15 minute intervals after the sample has been on the cylinder for a period of 45 minutes.

Summary of computation:

$$H = \frac{E \times I}{4.158 \times 252 \times (T_c - T_i)} \qquad (14)$$

Table 17. Energy Required to Maintain a Constant Cylinder Temperature with Untreated and with Metallized Samples

Sample Number	11
Material	Nylon
Weave	2 x 2 Basket
Thickness	0.015 Inches
Construction	97 x 60
Warp	260/17
Filling	260/17
Weight	5.78 oz/yd^2
Yarn Type	Filament
Densometer	46 Seconds

Sample	Temperature of Cylinder Degrees F. (T_c)	Heating Element Volts (E)	Heating Element Amperes (I)	Temperature of Cold Chamber Degrees F. (T_i)	Btu/second/ Degree F. x 10^{-5} (H)
Untreated	97.2	2.83	1.05	33.0	4.39
Metallized	99.2	2.83	1.05	32.5	4.22

All of the above data represents the average of three readings taken at 15 minute intervals after the sample has been on the cylinder for a period of 45 minutes.

Summary of computation:

$$H = \frac{E \times I}{4.158 \times 252 \times (T_c - T_i)} \qquad (14)$$

Table 18. Energy Required to Maintain a Constant Cylinder Temperature with Untreated and with Metallized Samples

Sample Number	12
Material	Nylon
Weave	4 x 4 Basket
Thickness	0.014
Construction	97 x 60
Warp	260/17
Filling	260/17
Weight	5.61 oz/yd^2
Yarn Type	Filament
Densometer	29.1 Seconds

Sample	Temperature of Cylinder Degrees F. (T_c)	Heating Element Volts (E)	Heating Element Amperes (I)	Temperature of Cold Chamber Degrees F. (T_i)	Btu/second/ Degree F. x 10^{-5} (H)
Untreated	98.4	2.80	1.04	37.0	4.59
Metallized	99.8	2.78	1.03	37.0	4.32

All of the above data represents the average of three readings taken at 15 minute intervals after the sample has been on the cylinder for a period of 45 minutes.

Summary of computation:

$$H = \frac{E \times I}{4.158 \times 252 \times (T_c - T_i)} \qquad (14)$$

Table 19. Energy Required to Maintain a Constant Cylinder Temperature with Untreated and with Metallized Samples

Sample Number	13
Material	Nylon
Weave	5 Harness Satin
Thickness	0.016 Inches
Construction	97 x 65
Warp	260/17
Filling	260/17
Weight	6.13 oz/yd^2
Yarn Type	Filament
Densometer	16.3 Seconds

Sample	Temperature of Cylinder Degrees F. (T_c)	Heating Element Volts (E)	Heating Element Amperes (I)	Temperature of Cold Chamber Degrees F. (T_i)	Btu/second/ Degree F. x 10^{-5} (H)
Untreated	99.3	2.80	1.04	36.2	4.46
Metallized	101.2	2.80	1.04	36.2	4.33

All of the above data represents the average of three readings taken at 15 minute intervals after the sample has been on the cylinder for a period of 45 minutes.

Summary of computation:

$$H = \frac{E \times I}{4.158 \times 252 \times (T_c - T_i)} \qquad (14)$$

Table 20. Percent Increase in Thermal Insulating Value of Metallized over Untreated Fabrics For Sample Numbers 9 through 13

Sample Number	Energy Input to Cylinder Untreated Sample Btu/Second/ Degree F. x 10^{-5} (t_{cu})	Energy Input to Cylinder Metallized Sample Btu/Second/ Degree F. x 10^{-5} (t_{cm})	Percent Increase in T.I.V.
9	4.36	4.21	13.2
10	4.39	4.23	15.3
11	4.39	4.22	14.4
12	4.59	4.32	28.6
13	4.46	4.33	12.5

Summary of computation:

$$\text{Percent Increase in T.I.V.} = \frac{(t_o - t_{cm}) - (t_o - t_{cu})}{(t_o - t_{cu})} \qquad (13)$$

Ho. is the Btu/Second/Degree F. input to the cylinder when the cylinder was not covered with one of the sample fabrics. The value of t_o was determined to be 5.50×10^{-5}

Table 21. Emissivities of Untreated Samples

Sample Number	Potentiometer Reading (E_s)	Emissivity (E)
1	8.0	0.96
2	7.6	0.92
3	7.9	0.96
4	8.1	0.98
5	8.1	0.98
6	8.2	0.99
7	8.0	0.96
8	8.1	0.98
9	8.1	0.98
10	8.0	0.96
11	8.0	0.96
12	8.2	0.99
13	8.1	0.98

Potentiometer reading for a black body at 110°F. was 8.3,(E_b).

All determinations were made with the sample temperature at 110.0°F.

Summary of computation:

$$E = \frac{E_s}{E_b}$$

Table 22. Emissivities of Metallized Samples

Sample Number	Potentiometer Reading (E_s)	Emissivity (E)
1	4.6	0.55
2	5.0	0.60
3	5.1	0.61
4	5.6	0.67
5	5.9	0.71
6	6.2	0.75
7	6.9	0.83
8	7.0	0.84
9	4.7	0.56
10	4.6	0.55
11	4.6	0.55
12	3.6	0.41
13	4.9	0.59

Potentiometer Reading for a black body at 110.0°F. was 8.3 (E_b).

All determinations were made with the sample temperature at 110.0°F.

Summary of computation

$$E = \frac{E_s}{E_b}$$

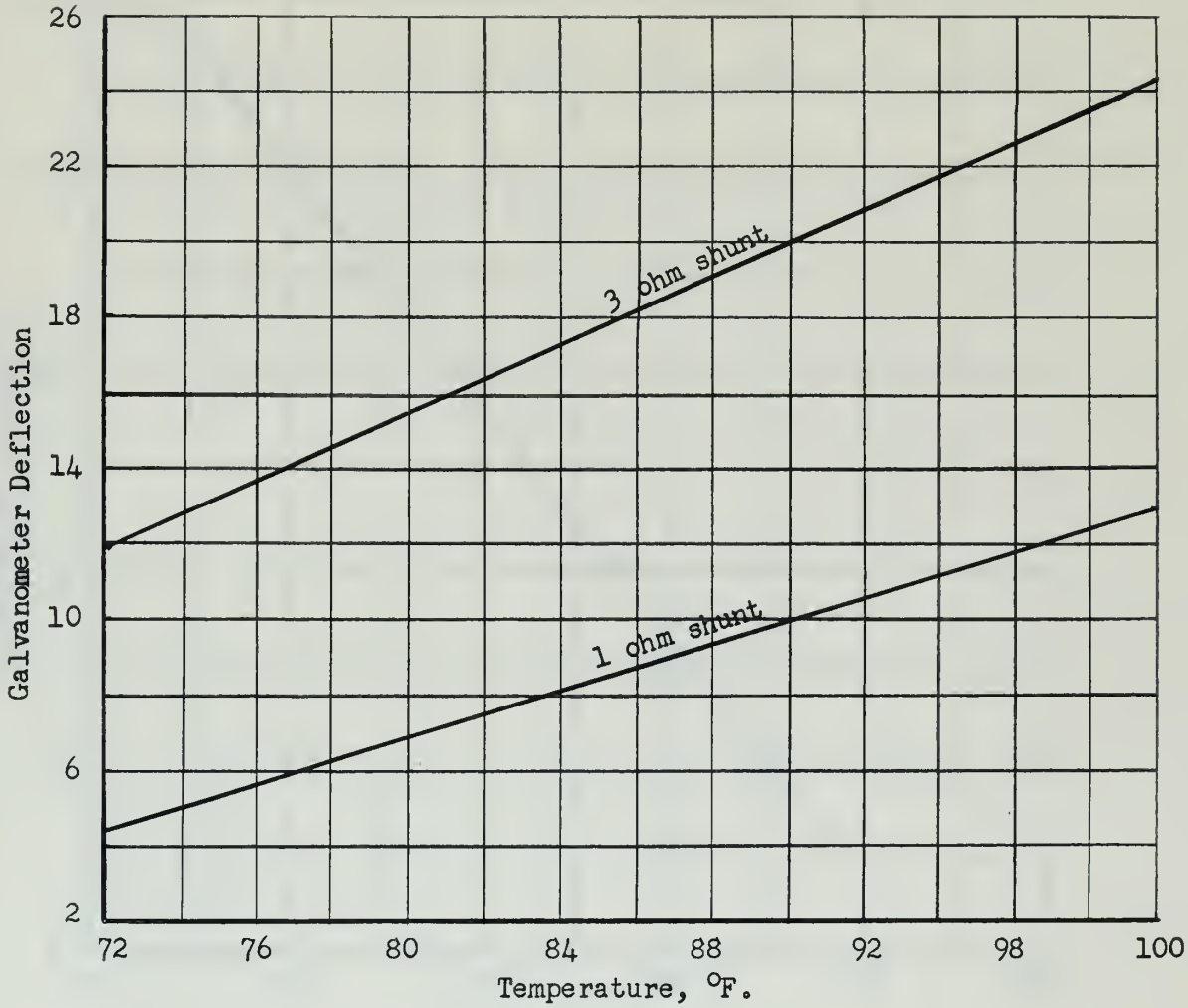


Figure 11. Thermocouple Calibration Curve, Temperature vs. Galvanometer Deflection

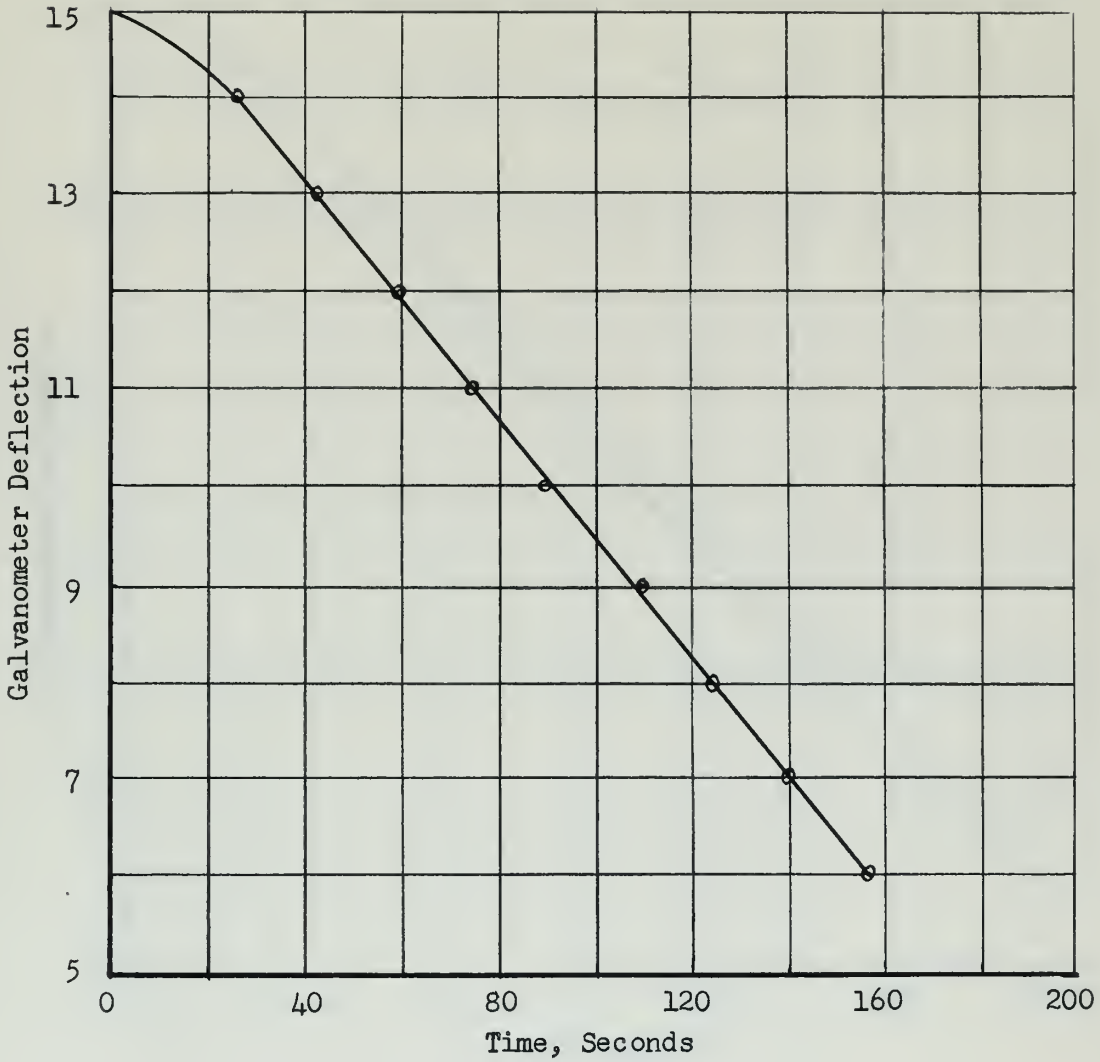


Figure 12. Cooling Curve of Cylinder Without Sample, Environmental Temperature -22°F., Temperature vs. Time

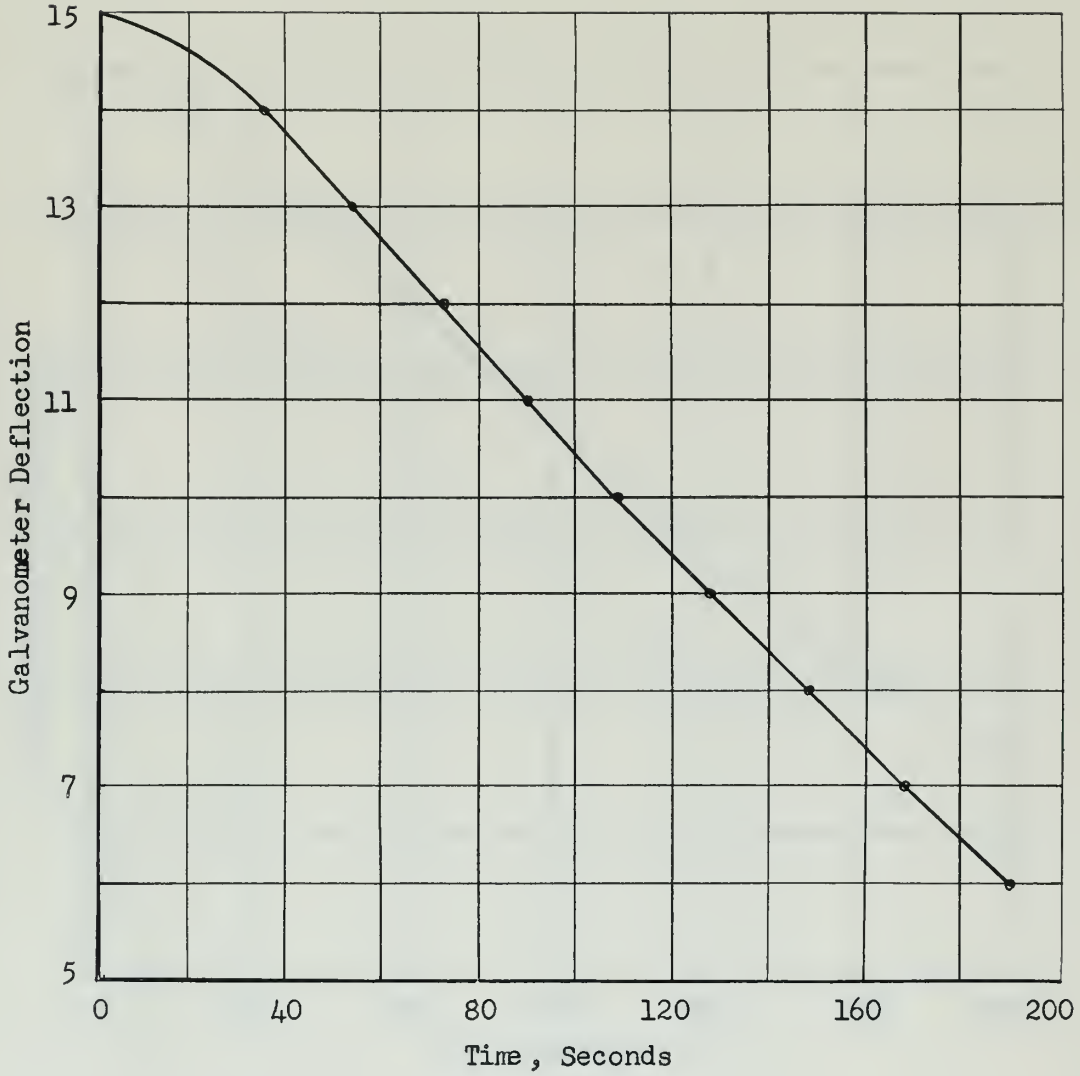


Figure 13. Cooling Curve of Cylinder Without Sample, Environmental Temperature 0.0°F., Temperature vs. Time

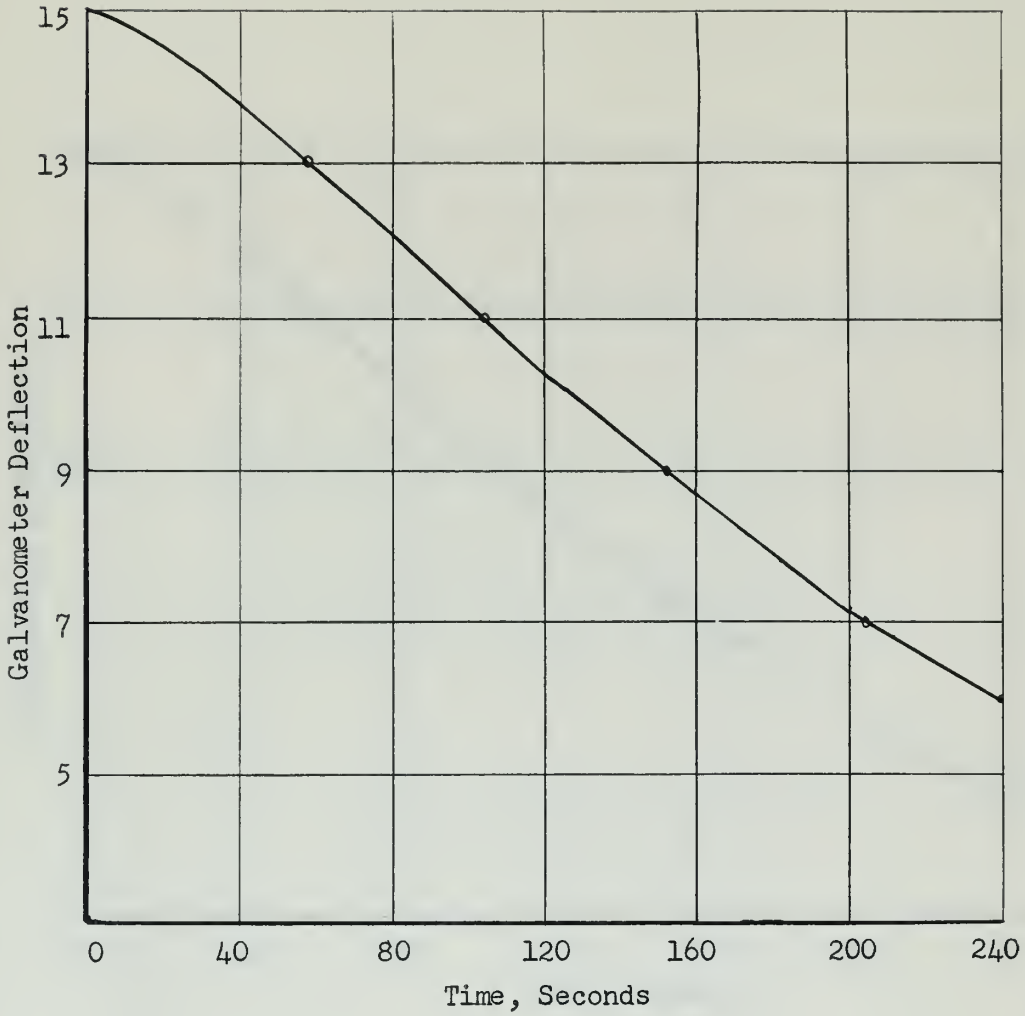


Figure 14. Cooling Curve of Cylinder Without Sample, Environmental Temperature 20°F., Temperature vs. Time

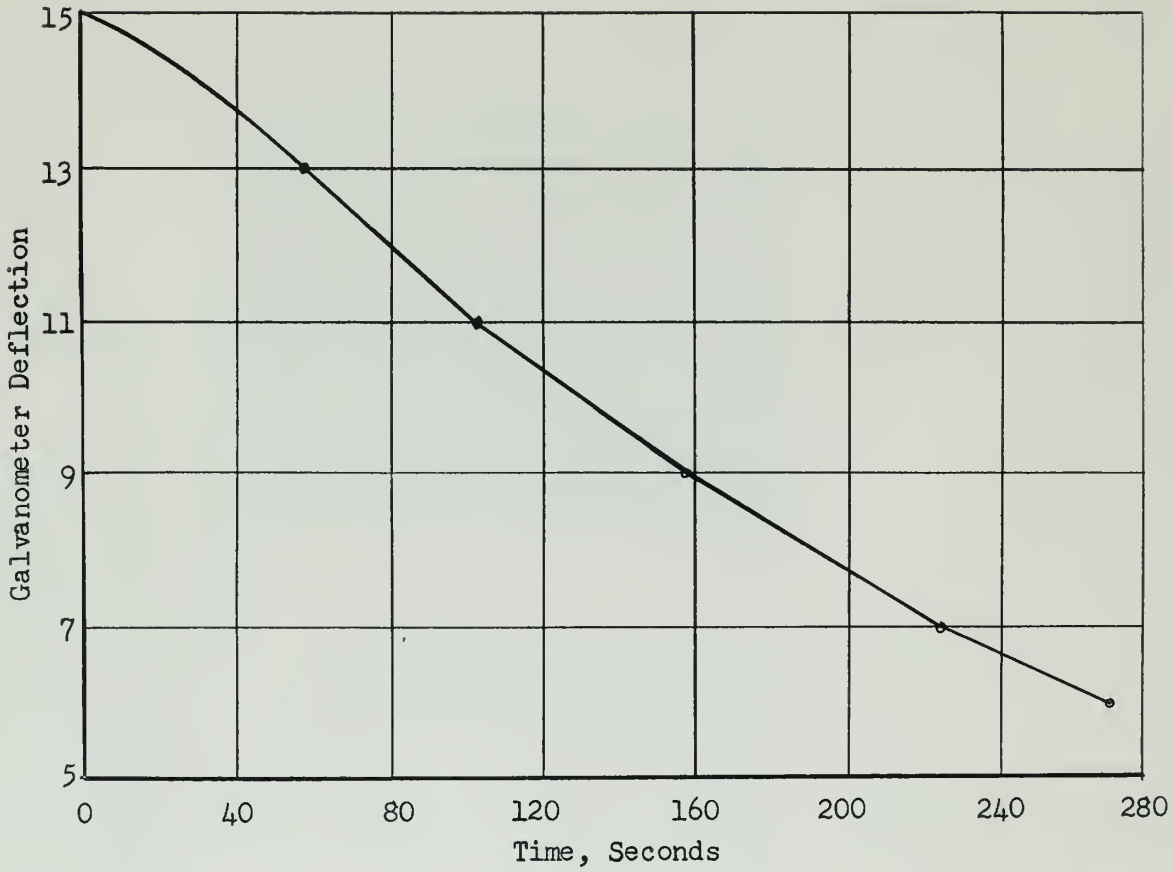


Figure 15, Cooling Curve of Cylinder Without Sample, Environmental Temperature 34°F., Temperature vs. Time

Thesis 27987
A455 Anderson
Effect of thin metal films on the thermal transmission properties of textile fabrics.